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PREDICTIONS OF HUMAN TOLERANCE TO COLD WATER IMMERSION WHILE WEARING ADVANCED INTEGRATED GARMENT ENSEMBLES WITH AND WITHOUT SURVIVAL RAFTS OR EXOGENOUS HEATING

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INTRODUCTION

US Navy interest in garments providing integrated protection against chemical agents, hyperthermia, hypobaria, and hypothermia has led to fabrication of prototype multi-purpose garments. As part of the development process, these garments need to be tested for the protection they provide against these hazards. Mathematical modeling can be used to simulate the thermal protection provided by the various garment designs and minimize laboratory testing. It can also be used to establish guidelines on the amount of clothing insulation required to withstand exposures of various durations under conditions of thermal stress.

This paper reports on the theoretical evaluation of hypothermia protection provided by various tactical aircrew garments during simulated head-out cold water immersion (CWI) using the Texas Human Thermal Model (10) (referred to THTM, below), as modified by the Naval Air Warfare Center Aircraft Division Warminster for use with low CLO values (7). THTM can aid in clothing design by allowing specification of insulation values for up to fifteen body segments. This is an improvement over earlier work (8), in which researchers based their conclusions on an overall mean CLO value for garments. Also included in this paper is an algorithm to predict the effects of using open and closed survival rafts while wearing a CWU-62/P on rectal and mean skin temperature during survival scenarios. Lastly, THTM was used to predict the amount of exogenous heating required to survive 6 hour CWI while wearing CWU-27/P and CWU-62/P garment ensembles.

METHODS

Changes in physiological temperatures were predicted by THTM for nude and clothed immersions (see Table 1). Estimates were based on an idealized individual weighing 72.6 kg (160 lbs) with a mean skinfold thickness of 10 mm. The individual was in a relaxed sitting posture with a basal metabolic rate of 100 watts. Comparisons between garments were based on the predicted physiological response to accidental head-out immersion lasting up to 6 hours in -2.2°C (28°F) and 4.4°C (40°F) water. Estimates of rectal temperature (T_{re}), mean skin temperature (T_{sk}) and central temperature (T_c) were generated as a function of immersion time. T_c was defined as the predicted temperature located in the head at the level of the hypothalamus. Changes in T_{re} and T_{sk} as a function of exposure time were given by $\Delta T_k = T_{k_{initial}} - T_{kt}$, where k = re or sk and t refers to a point in time during the exposure. The maximum possible exposure duration for each garment in each environment was defined as either completion of the 6 hour immersion, the time at which T_{re} reached 35°C (11) or the point at which the THTM predicted metabolic fatigue. Fatigue occurred when the energy derived from aerobic metabolism was exhausted with a concomitant buildup of lactic acid (the byproduct of anaerobic metabolism), at which point shivering ceased. THTM indicated that fatigue had been reached by a transient rise in T_c.

THTM separates the body into fifteen regions, head, chest, abdomen, right and left thighs, calves, feet, biceps, forearms and hands. A CLO value can be specified for each area. Regional insulation values for each garment were obtained from measurements using an immersed copper manikin either by the Naval Clothing and Textile Research Facility, Natick, MA or the CORD Group Limited, Dartmouth, Nova Scotia and are given in Table 1. Separate CLO values were not available for the thighs and calves or the biceps and forearms. Therefore, these regions were combined as shown in Table 1. The ensembles included the CWU-27/P (standard USN summer tactical assembly with helmet and CSU-13B/P anti-G suit), the CWU-62/P (standard USN tactical anti-exposure assembly with a CSU-13B/P) and seven prototype garments described in Table 2. Table 2 distinguishes between these ensembles by specifying which body regions were covered by pressure bladders. All of these garments are lightweight ensembles except for the CWU-62/P and #4 (also an anti-exposure garment).

CLOTHING ENSEMBLE	Head	Chest	Abdomen	Rt Arm	Lt Ar	Rt Hand	Lt Hand	Rt Leg	Lt Leg	Rt Foot	Lt Foot
Nude	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
CWU-62/P *	.18	.77	.77	.13	.13	.03	.03	.60	.60	.48	.48
1*	.03	.03	.03	.02	.02	.02	.02	.04	.04	.15	.15
2 *	.03	.03	.03	.07	.07	.03	.03	.04	.04	.11	.11
3 *	.03	.03	.03	.07	.07	.03	.03	.07	.07	.14	.14
CWU-27/P *	.03	.03	.03	.02	.02	.01	.01	.05	.05	.16	.16
4	.16	.81	.89	.14	.13	.22	.18	.31	.38	.56	.67
5-U	.10	.10	.06	.08	.07	.08	.07	.07	.06	.25	.30
5-I	.09	.17	.07	.11	.11	.08	.07	.06	.06	.23	.28
CWU-27/P	.05	.05	.11	.04	.03	.06	.06	.09	.10	.19	.23
6	.05	.08	.09	.05	.04	.05	.05	.09	.10	.19	.23
7	.05	.06	.06	.04	.03	.05	.04	.08	.09	.21	.28
8	.03	.09	.09	.03	.03	.04	.05	.07	.07	.17	.21

TABLE 1. Regional immersed CLO values measured using a copper manikin. Those marked with an asterisk were measured at the Naval Clothing and Textile Research Facility (Natick, MA) and those unmarked were measured by CORD Group Limited (Dartmouth, Nova Scotia). All garments were uninflated when tested except where noted below. Description of ensembles and coding is given in Table 2. Key: U: uninflated; I: inflated.

Ensemble	Foot	Leg	Thigh	Abdomen	Buttocks	Back/ Chest	Upper Arm	Lower Arm	Hand
1[a]	0	1	1	1	1	1	0	0	0
2[a]	0	2[b]	2	1	1	1	2	2	1
3	2	1	1	1	1	1	2	2	1
4	0	2	2	1	1	1	0	0	0
5[a,c]	2	1	1	1	1	1	2	2	1
6	0	1	1	1	0	1	0	0	0
7	2	2	2	1	1	1	0	0	0
8	0	1	1	1	0	1	0	0	0
CWU-27/P	0	1	1	1	0	0	0	0	0
CWU-62/P	0	1	1	1	0	0	0	0	0

Table 2. Prototype garment description. Ensembles 1-8 and CWU-27/P were tested with a HGU helmet, flight boots and flight gloves. CWU-62/P had a HAU-32/P inflatable hood and HAU-12/P inflatable mittens. Table indicates areas covered by pressure bladders, which are impermeable to water vapor. KEY: 0 - No coverage by pneumatic bladder; 1 - Pneumatic bladder opposed by fabric; 2 - Circumferential containment by pneumatic bladder; a - Ensemble with pneumatic bladders are integrated into a one-piece garment (The remaining ensembles are two-piece configurations consisting of an upper and lower garment); b - Lower leg coverage limited to just below the calf. Approximately half the lower leg segment is covered longitudinally; c - ensemble tested inflated and uninflated.

To model survival rafts, T_{re} and T_{sk} were obtained from four volunteer subjects in a 1988 study conducted at the Naval Air Development Center comparing the 18U (open), LR1 and 23U (both closed) rafts. T_{sk} was calculated according to equation 1 (10).

Eqn 1. $$T_{sk} = 0.07(T_{head}) + 0.07(T_{biceps}) + 0.27(T_{chest}) + 0.09(T_{abdomen}) + 0.07(T_{forearm}) + 0.11(T_{hand}) + 0.16(T_{thigh}) + 0.16(T_{calf})$$

During that study, subjects wearing the CWU-62/P entered a chilled pool of water for five minutes, then climbed into a raft. After bailing out as much water as possible, they remained in the raft for a total of two hours from the beginning of the immersion. It took subjects an average of 7.5 minutes to enter the raft. Raft bailing took a maximum of 25 minutes to complete. Following bailing, subjects were not required to perform any heavy physical activity until the exposures were completed.

Raft simulations were based on a simplification of the average physical requirements of the experimental trials. During the period including immersion, entering and bailing the raft, considerable physical activity was required of the subjects. This was followed by a relatively inactive period. To simulate this, during the first 32.5 minutes (sum of immersion, entering and bailing the raft times), THTM was run under the standard CLO configuration (see Table 1) but with the exercise metabolic rate (EMR) increased to 50 watts from the resting 1 watts. For the remaining 87.5 minutes, the EMR was set back to the resting level. This configuration served to model the open raft condition. During closed raft experimental trials, the head and torso of the human subjects were out of the water, theoretically resulting in warming and a limited amount of drying of the garment.

It was assumed that once an individual was in a raft and most of the bailing had been completed, the overall effective insulation of the anti-exposure garment/closed raft combination would improve. To model this projected improvement, the simulated environment was changed from water to air after the simulated bailing period. This led to unrealistically high body segment temperatures which maintained a plateau rather than the continuous drop exhibited in experimental trials. It was also found that increasing the CLO vales of all body segments was unrealistic, given the fact that in these particular rafts, the legs remained immersed even after bailing. The best fit to the actual data was derived by increasing the head and torso CLO values only. In choosing the level to increase the insulation, a compromise was reached between higher T_{re} and a realistic rise in T_{sk} after the 32.5 minute increased activity period. Results were evaluated by supplementing the standard immersed CLO values by adding 1/8, 1/4 or 1/2 times the difference between dry and immersed CWU-62/P head and torso CLO values. As CLO increased, T_{re} increased but there was a transient rise in T_{sk} after EMR returned to the resting level. Using the 1/4 and 1/2 increments, this rise in T_{sk} was too pronounced when compared to the experimental data. The one-eighth increase in CLO values was determined to be the best fit for our human data set (i.e., head CLO = 0.31 and chest and abdomen CLO = 1.15).

In order to test this scenario, the physical characteristics of the human subjects were input into THTM and ΔT_{re} and ΔT_{sk} were predicted. To convert percent body fat data obtained from the human subjects to mean skinfold thickness (mm) as required by THTM, a nonlinear regression was calculated from data published by Strong, *et al* (9) ($r^2 = 0.999$), as

Eqn 2. $$MST = 2.2077 + 0.3078\,x + 0.0007\,x^3 + 8.96*10^{-12}\,e^x + 21.0186\,e^{-x}$$

where x = percent body fat. To gauge how well THTM predictions followed actual values over time immersed, a regression analysis on ΔT_{re} and ΔT_{sk} was performed and the correlation coefficient (r^2) was calculated. Statistical analyses included paired two-way t-tests, with a level of significance set at $p = 0.05$.

To model the effects of adding exogenous heating to the subject, the following assumptions were made. First, it was assumed that 60% of the heat supplied would be retained by the body. The remainder would be lost to the environment. Second, of the heat retained by the body, it was necessary to specify how much heat each of the eight skin segment layers included in THTM would retained. The relative amounts were assumed to be (from outermost to innermost layer) 40%, 30%, 20%, 5%, 5%, 0%, 0%, and 0%. This distribution does not preclude heat transport to the three deepest layers by conduction and convection.

RESULTS

1. GARMENT ENSEMBLE MODELING:

None of the modeled garments were predicted to provide sufficient thermal protection to survive a simulated 6 hour -2.2 or 4.4°C CWI. Table 3 contains the predicted times to reach 35°C T_{re} and fatigue in -2.2 or 4.4°C water for the various garments (nude results are included for comparison). Note that reaching 35°C T_{re} occurred within 10 minutes of reaching fatigue (mean values were essentially equal). There were no statistically significant differences among the various light-weight tactical ensembles relative to predicted survival time in -2.2 or 4.4°C water ($p = 0.50$ and $p = 0.448$, respectively). For estimated time to reach metabolic fatigue in -2.2 or 4.4°C water, $p = 0.683$ and $p = 0.673$, respectively. This excluded the anti-exposure garments; #4 and CWU-62/P.

Two hour 4.4°C CWI were successfully completed when garment #4 and CWU-62/P were used. Figures 1-3 display predicted T_{re} as a function of time during 4.4°C CWI (see Figures 4-6 for -2.2°C water T_{re} results). Figures 7-9 display predicted T_{sk} as a function of time during 4.4°C water immersion (see Figures 10-12 for -2.2°C water T_{sk} results). In each figure, the nude predictions are shown for comparison.

Note that the CWU-27/P appears twice in Table 3, using CLO values measured by CORD and Natick. As shown in Figures 1, 3, 7 and 9, the warmer CLO values for the CWU-27/P measured by CORD led to different THTM predictions for T_{re} and T_{sk}. Temperatures at fatigue for the CWU-27/P are listed in Table 4. The higher CORD CLO values in the torso and legs account for the relatively larger disparity between the T_{sk} estimates as compared to T_{re}. Linear regression equations relating 4.4°C and -2.2°C estimated T_{re} for CWU-27/P are given in Table 5.

GARMENT	WATER TEMP °C	TIME (min) TO REACH T_{re} = 35 °C	TIME (min) TO REACH METABOLIC FATIGUE
CWU-62/P	4.4	224	224
4	4.4	175	185
5-inflated	4.4	57	65
6	4.4	53	55
5-uninflated	4.4	52	55
8	4.4	52	55
CWU-27/P	4.4	51	50
7	4.4	51	50
3*	4.4	48	47
2 *	4.4	46	45
1 *	4.4	44	42
CWU-27/P *	4.4	44	42
NUDE	4.4	38	38
Lightweight garment means:		50 ± 4	51 ± 7
CWU-62/P	-2.2	136	141
4	-2.2	110	120
5-inflated	-2.2	45	45
6	-2.2	41	40
5-uninflated	-2.2	42	45
8	-2.2	40	40
CWU-27/P	-2.2	40	40
7	-2.2	39	40
3*	-2.2	38	37
2*	-2.2	36	36
1*	-2.2	34	34
CWU-27/P *	-2.2	34	34
NUDE	-2.2	30	32
Lightweight garment means:		39 ± 4	39 ± 4

TABLE 3. Predicted times to reach fatigue and 35°C T_{re} for nude and clothed conditions. Lightweight garment means plus one standard deviation shown do not include heavyweight garments (CWU-62/P and 4) or nude values. * = CLO values measured at Natick. Abbreviations are the same as in Table 2.

Measured by	Water Temp. (^oC)	T_{re} at Fatigue (^oC)	T_{sk} at Fatigue (^oC)	Time to Fatigue (minutes)
CORD	-2.2	35.0	5.3	40
Natick	-2.2	35.0	2.7	35
CORD	4.4	35.1	10.6	50
Natick	4.4	35.0	8.3	45

TABLE 4. Model rectal and mean skin temperature estimates at fatigue based upon the CWU-27/P CLO values measured by CORD and Natick.

Water temp (^oC)	Equation	Standard Error of Y_{est}	r^2
4.4	$T_{cd} = 0.847\ (T_{nat}) + 5.704$	0.036	0.998
-2.2	$T_{cd} = 0.831\ (T_{nat}) + 6.311$	0.043	0.998

TABLE 5. Linear regression equations relating rectal temperature estimates based on CWU-27/P CLO values supplied by CORD and Natick. T_{cd} is the T_{re} based on CORD CLO; T_{nat} is the T_{re} based on Natick CLO; Y_{est} is the prediction error; r^2 is the regression fit.

2. RAFT MODELING:

Three raft types were included in the human data set used to develop this simulation: an open raft (18U) and two closed rafts (23U and LR1). Figures 13 and 14 compare the changes in T_{re} and T_{sk}, respectively, predicted using the raft simulation to mean human thermal responses. Note that in these figures, there was a transient drop in human T_{re} during the initial immersion. THTM, however, included an initial vasoconstriction response which produced a 15 to 20 minute increase in T_{re}. Despite efforts to model this brief drop in T_{re} (including running the Model under nude conditions), it was not possible to recreate and was neglected in the simulation.

The use of a raft under CWI conditions will likely increase the time required for T_{re} to drop to 35°C. After two hours in 4.4°C water while wearing a CWU-62/P, the predicted T_{re} was 35.6°C. After two hours in a closed raft wearing the same outfit, the predicted T_{re} was 35.8°C, while in an open raft, the predicted T_{re} was 35.6°C.

Figures 15-20 show the comparisons between actual and predicted ΔT_{re} in closed and open raft CWI scenarios. All of the human subjects had either a rise or a relatively stable plateau during the initial high activity period, followed by a decline in ΔT_{re}. As can be seen from the figures, some predictions were better than others though the shape of the predicted curves were similar. Table 6 contains the r^2 values for predicted vs actual ΔT_{re} and ΔT_{sk}. As can be seen, except for predicted ΔT_{re} for subject B in the LR1 raft and ΔT_{sk} for three subjects in closed raft, THTM was able to faithfully predict the overall trends over the 2 hour CWI ($r^2 > 0.836$ for ΔT_{re} and $r^2 > 0.84$ for ΔT_{sk}). The open raft predictions tended to be conservative during the inactive portion of the simulation, except for Subject A.

Figures 21-26 show the comparisons between actual and predicted ΔT_{sk} in closed and open raft scenarios. While the abrupt rise in predicted ΔT_{sk} during the closed raft simulation is unrealistic, all of the subjects did demonstrate a transient increase during their exposure. The predicted ΔT_{sk} curve shapes for the open raft simulations were consistent with the actual curves, particularly during the first twenty minutes.

SUBJECT	RAFT TYPE	r^2 for ΔT_{re}	r^2 for ΔT_{sk}
A	LR1	0.930	0.871
A	23U	0.908	0.734
B	LR1	0.208	0.840
B	23U	0.923	0.902
E	LR1	0.952	0.903
E	23U	0.883	0.759
F	LR1	0.836	0.503
F	23U	0.953	0.890
A	18U	0.917	0.968
B	18U	0.856	0.962
E	18U	0.900	0.953
F	18U	0.900	0.965

TABLE 6. Correlation coefficients for comparisons between actual and predicted ΔT_{re} and ΔT_{sk} during CWI with subjects wearing a CWU-62/P and using a raft. LR1 and 23U were closed rafts while 18U was an open raft design.

3. INCREASING THERMAL TOLERANCE BY APPLYING AN EXOGENOUS HEAT SOURCE TO THE CWU-62/P DURING CWI:

This part of the investigation addressed the question, "during an accidental CWI, if exogenous heating was available, how powerful do the sources have to be to survive a six hour CWI?" Using THTM and the assumptions listed in the Methods section, it was predicted that a 1000 W external heating source and the CWU-62/P would enable the standard man to withstand six hours in 4.4°C water without fatigue (estimated T_{re} fell to 35.7 °C). In -2.2°C water, a 2250 W heating source with the CWU-62/P would be required to extend survival to the full six hours (T_{re} fell to 36.2 °C). With the CWU-27/P, 12000 W of external heating was predicted to be required to withstand six hours in 4.4°C water. Figures 27 and 28 show the predicted curves for the CWU-62/P and a range of heater outputs along with the standard (unheated) ΔT_{re} and ΔT_{sk} curves, respectively.

DISCUSSION

The results indicated that all of the garments modeled, except the CWU-62/P and ensemble #4, were incapable of maintaining T_{re} greater than 35°C after 2 hours CWI in 4.4°C water. This estimate of CWU-62/P hypothermia protection also held true at -2.2°C (suit #4 was predicted to reach critical T_{re} after 1 hour 50 minutes). Aircrew with equal or greater body fat than the idealized individual used in this modeling should have at least this degree of protection because of the increase in cold tolerance related to body fat (2).

Human CWI studies have generally produced results supporting these predictions for the CWU-62/P (5,8), though these tests were performed in 7.2°C (45°F) water. Most of the subjects in these studies, despite widely varying body fat thickness, maintained T_{re} above 35°C for 2 hours. It is not clear why some subjects with comparable amounts of body fat could not maintain their T_{re} above 35°C. One possible explanation is that metabolic responsiveness to cold exposure differs between individuals, even those with similar body fat content (2).

Model estimates for the time required to reach T_{re} = 35°C while wearing the CWU-27/P agreed with previous investigations. In these studies, the mean time to reach T_{re} = 35°C for volunteers immersed in 4.4°C water while wearing a CWU-27/P was approximately 50 minutes (4). As shown in Table 3, THTM predictions using the CORD CLO measurements for the CWU-27/P were closer to these results than estimates using the Natick CLO values.

Based on the CLO values listed in Table 1, it would have appeared that garment #4 should have been predicted to provide more effective insulation than the CWU-62/P. The authors have shown elsewhere (7) that THTM predicted CWI survival times could be increased by improving insulation (ordered from most to least effective) to the torso, leg, head, arm, foot then hand. Therefore, based on THTM algorithms, the 83 to 86% rise in hand insulation and 14 to 28% increase in foot insulation shown from garment #4 would do little to increase predicted survival times. The 5 to 13% greater torso insulation probably did not provide enough additional insulation to offset the 37 to 48% greater CWU-62/P leg CLO values. Furthermore, THTM predicted that an insulated hood (CWU-62/P) would maintain higher head temperatures than a helmet (ensemble #4), even though the difference in measured head CLO was negligible.

It was not surprising that there was no difference in the predicted insulation abilities of the prototype lightweight garments. Sensitivity analyses of THTM predictions (7) indicated that relatively large levels of foot and hand insulation do little to increase CWI tolerance. The difference in insulation value of clothing segments when CLO drops below 0.1 is minimal for these types of ensembles. For example, the mean torso CLO for these suits was 0.07, while the CWU-62/P torso CLO was an order of magnitude greater. In fact, the estimated time to fatigue for the CWU-62/P dropped by only 3.5 minutes for every 0.01 drop in torso CLO below 0.1.

Clothing alone appears to be insufficient to ensure two hour CWI survival in -2.2°C water. The increased amounts of insulation required to protect a non-heated individual may unacceptably restrict normal aircrew operation. Supplemental heating may enable aircrew to use the existing CWU-62/P ensemble under these conditions. However, clothing ensembles with less insulation, such as the CWU-27/P, would require an inordinate amount of exogenous heat to be feasible in emergency survival situations. Therefore, a balance between insulation and exogenous heating needs to be found to maximize protection against accidental CWI while minimizing interference with operational task performance.

Raft use was predicted to reduce heat loss to the environment, depending upon the type of raft used. It was predicted that T_{re} fell to 35°C after 225 minutes when wearing a CWU-62/P, with or without an open raft. The closed raft simulation estimated that it would have taken 298 minutes for T_{re} to reach 35°C, though the Model also predicted that fatigue would occur about 30 minutes earlier. This was consistent with human raft studies of impermeable garments with CLO values equal to or greater than those of the CWU-62/P. In these studies, subjects reached 35°C T_{re} in less than 300 minutes (1,3). It appears that the algorithm used to simulate raft exposures approximates human T_{re} responses faithfully.

SUMMARY

1. The CWU-62/P was predicted to provide sufficient insulation for most individuals to maintain rectal temperatures above 35°C for greater than two hours in water as cold as -2.2°C. It was also was predicted that garment #4 could maintain T_{re} above 35°C in 4.4°C water for two hours.

2. None of the lightweight garments modeled were predicted to provide adequate insulation to maintain rectal temperatures above 35°C for two hours in 4.4°C water.

3. Model estimates for the time required to reach 35°C T_{re} while wearing the CWU-62/P and CWU-27/P (using CORD measurements of CLO values) in 4.4°C water were consistent with human studies.

4. Model predictions for the time required to reach 35°C T_{re} using a combination of wearing a CWU-62/P and the simulated closed raft algorithm 4.4°C water were consistent with human studies.

5. By adding supplemental heating (1000 W for 4.4°C and 2250 W for -2.2°C water), the CWU-62/P is estimated to be adequate for maintaining T_{re} above 35°C for six hours.

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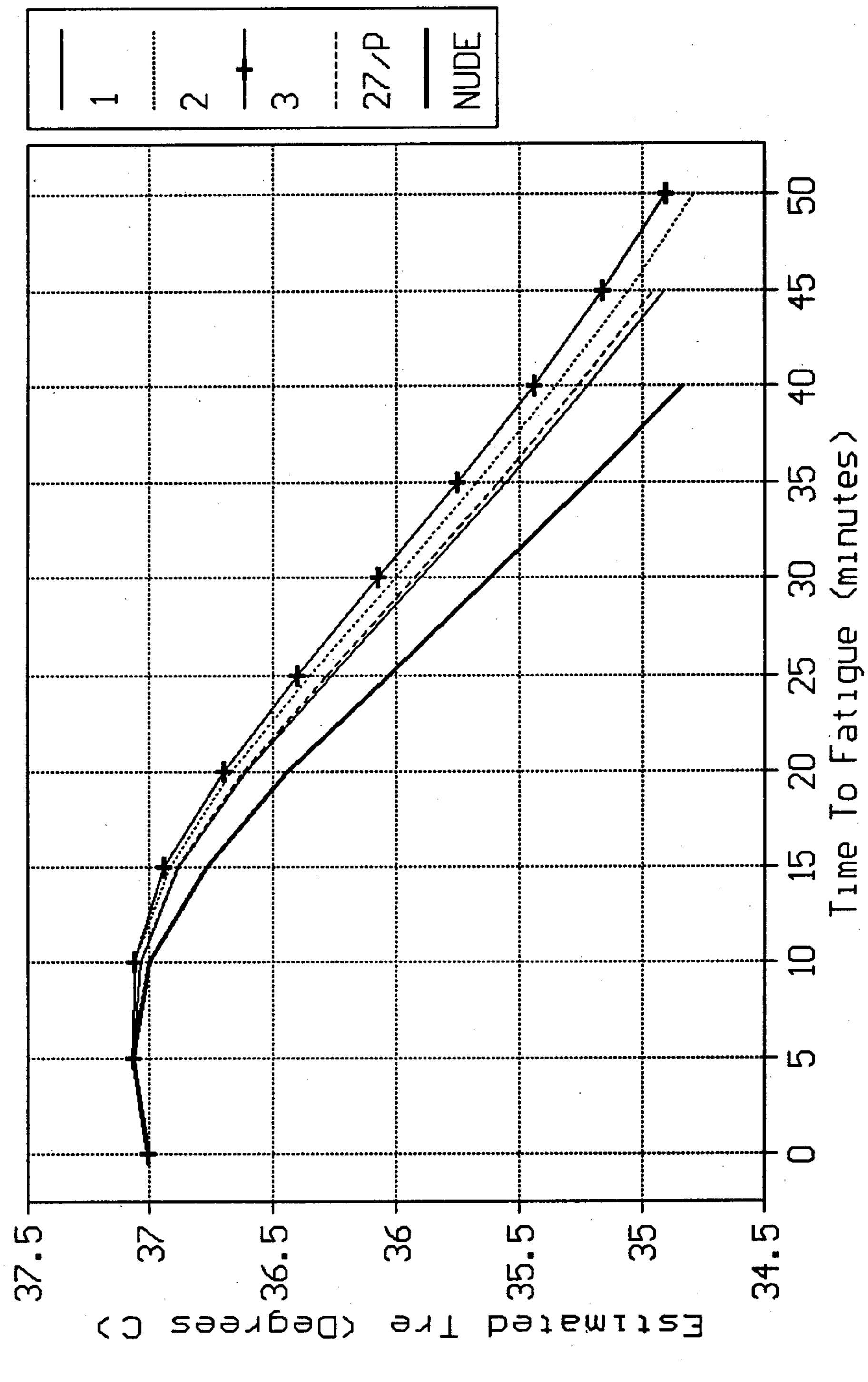

Figure 1. Estimated rectal temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by Navy Natick.

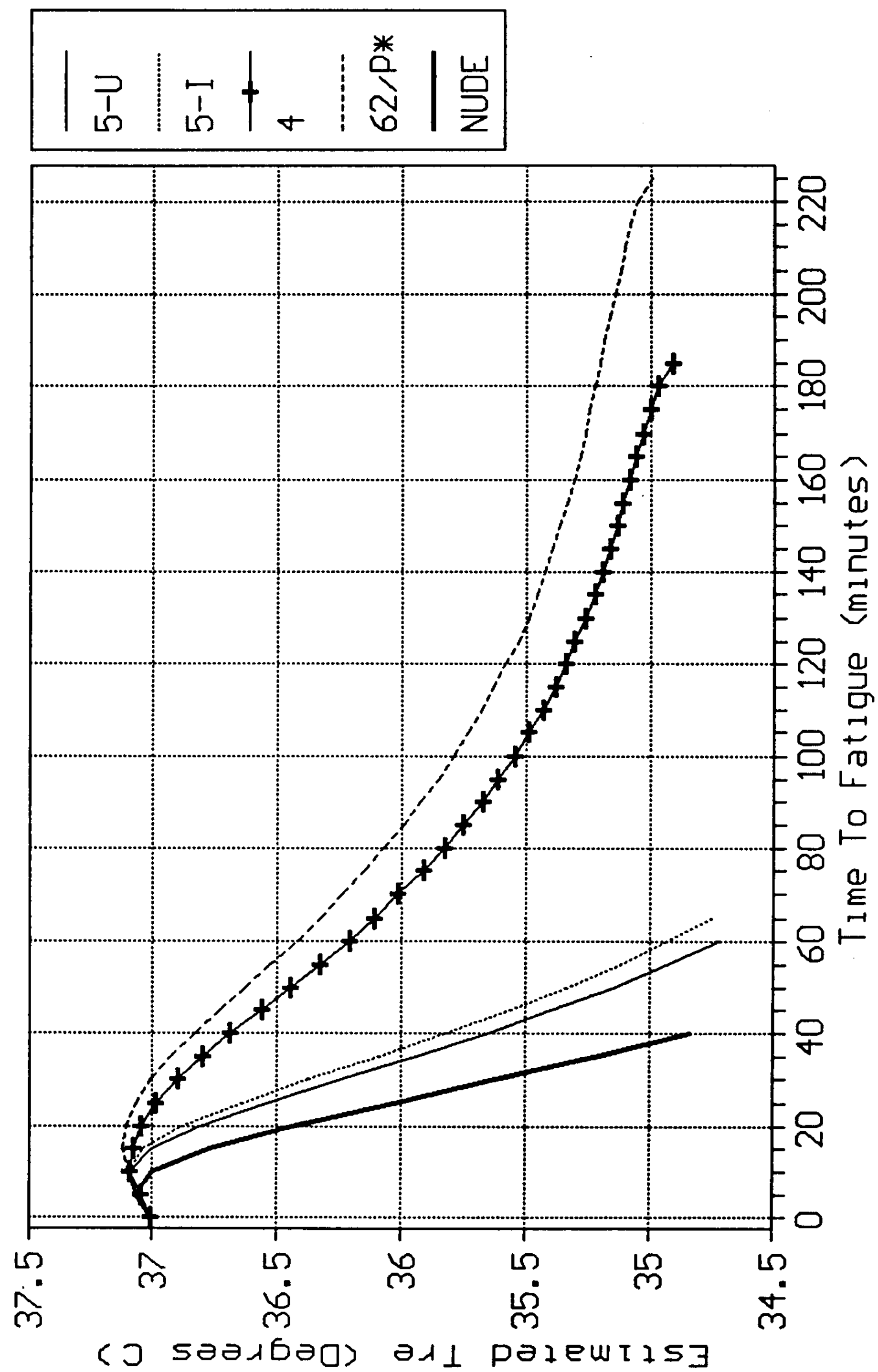

Figure 2. Estimated rectal temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by CORD. U: uninflated; I: inflated; *: CLO measured by Navy Natick.

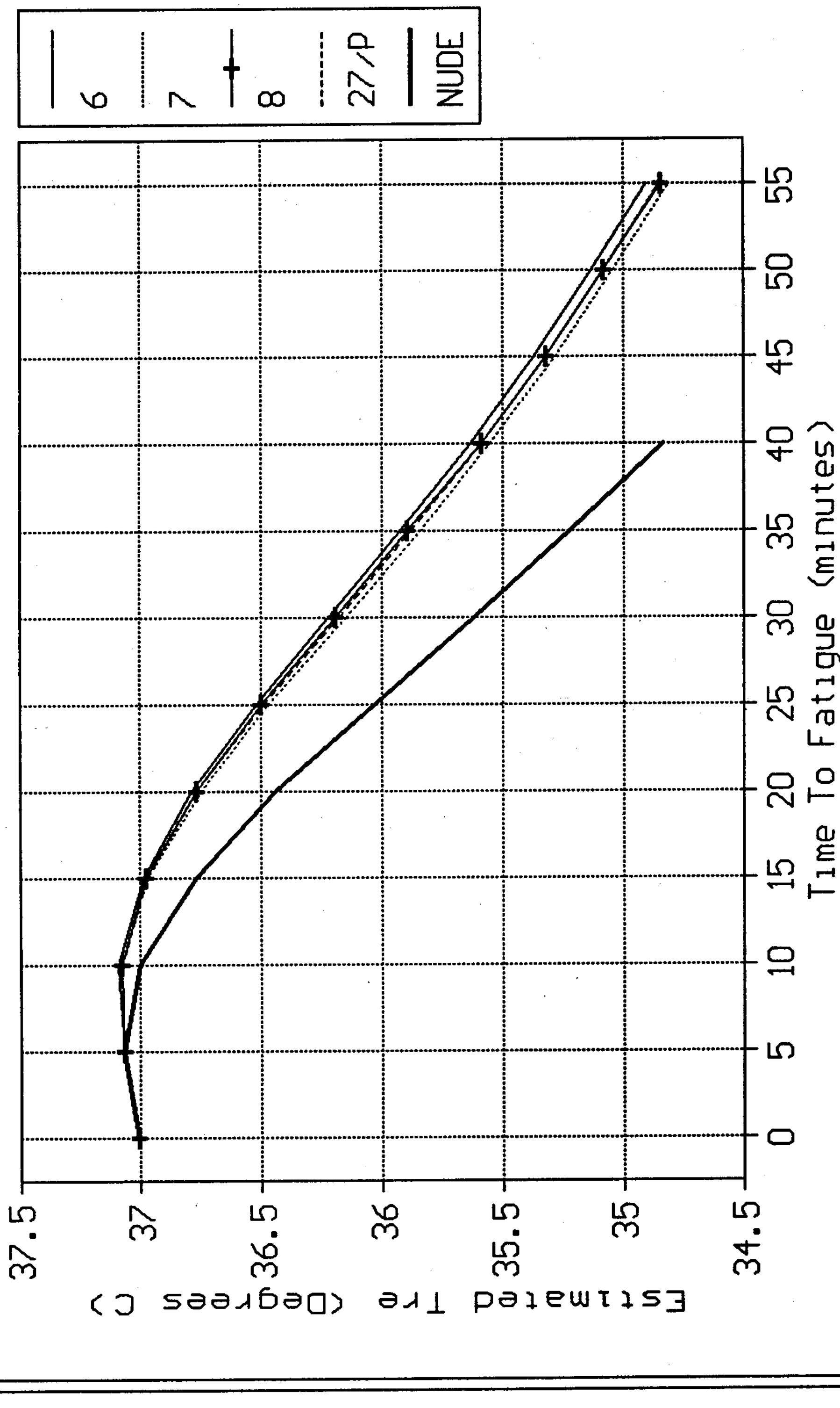

Figure 3. Estimated rectal temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by CORD.

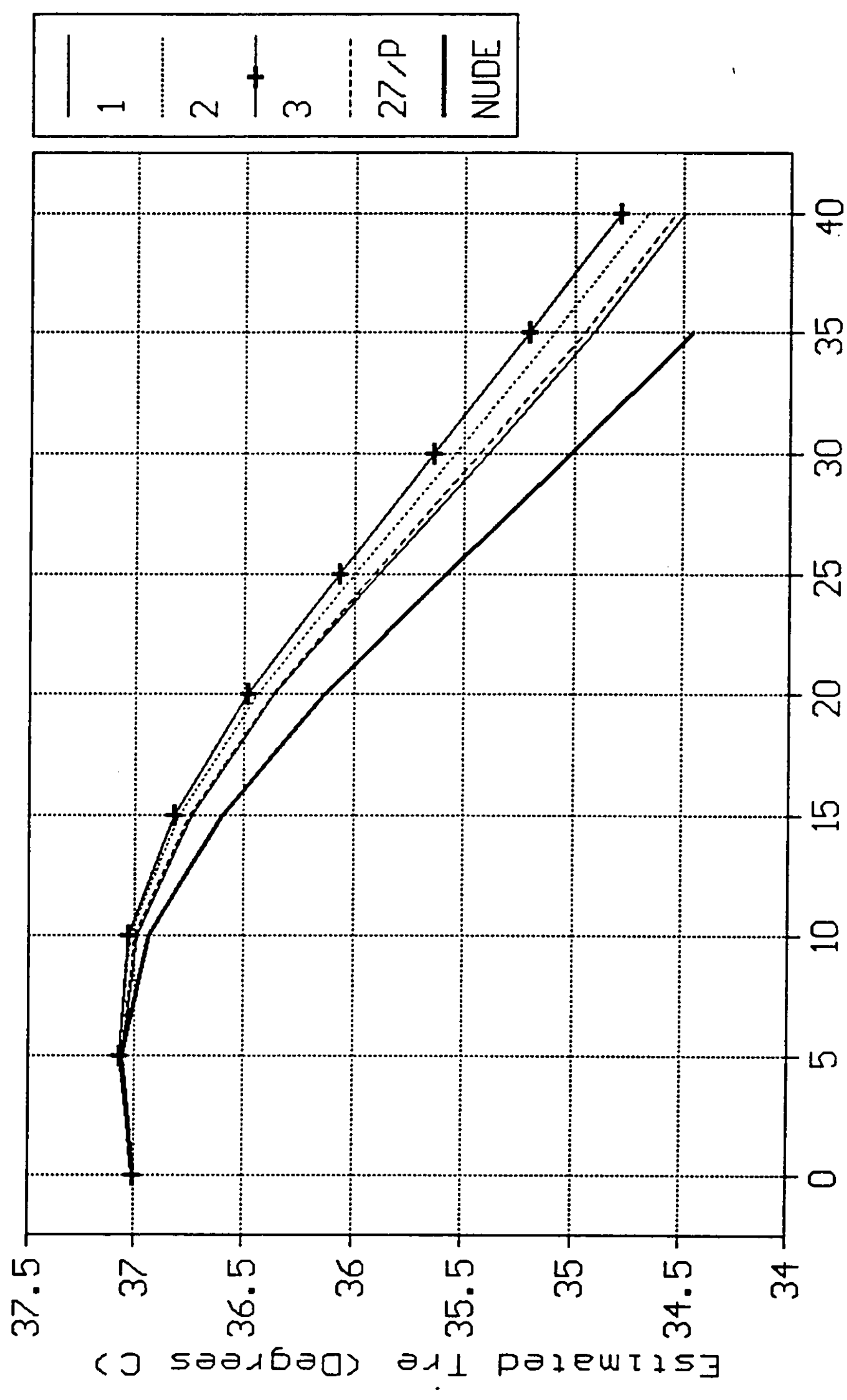

Figure 4. Estimated rectal temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by Navy Natick.

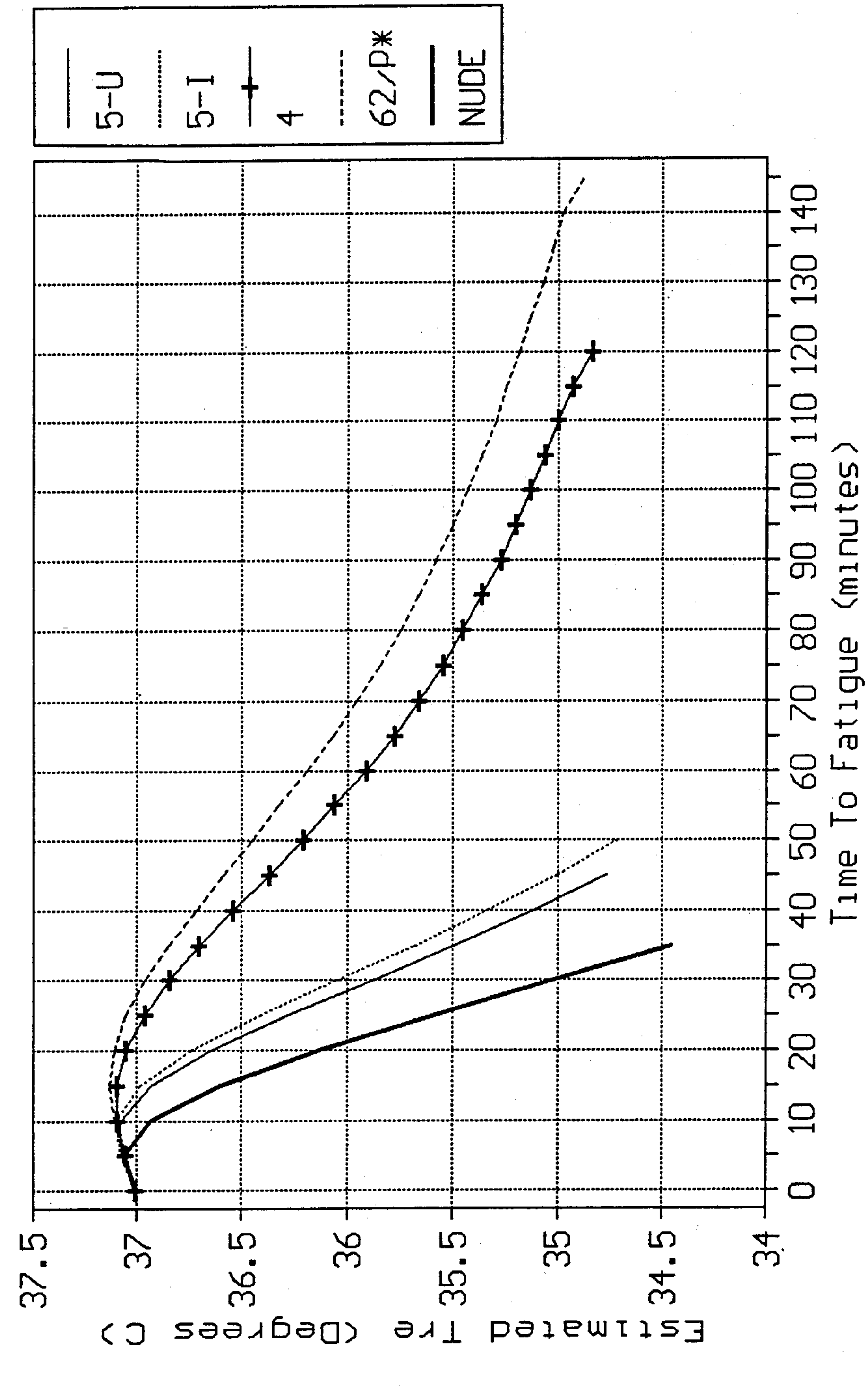

Figure 5. Estimated rectal temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by CORD. U: uninflated; I: inflated; *: CLO measured by Navy Natick.

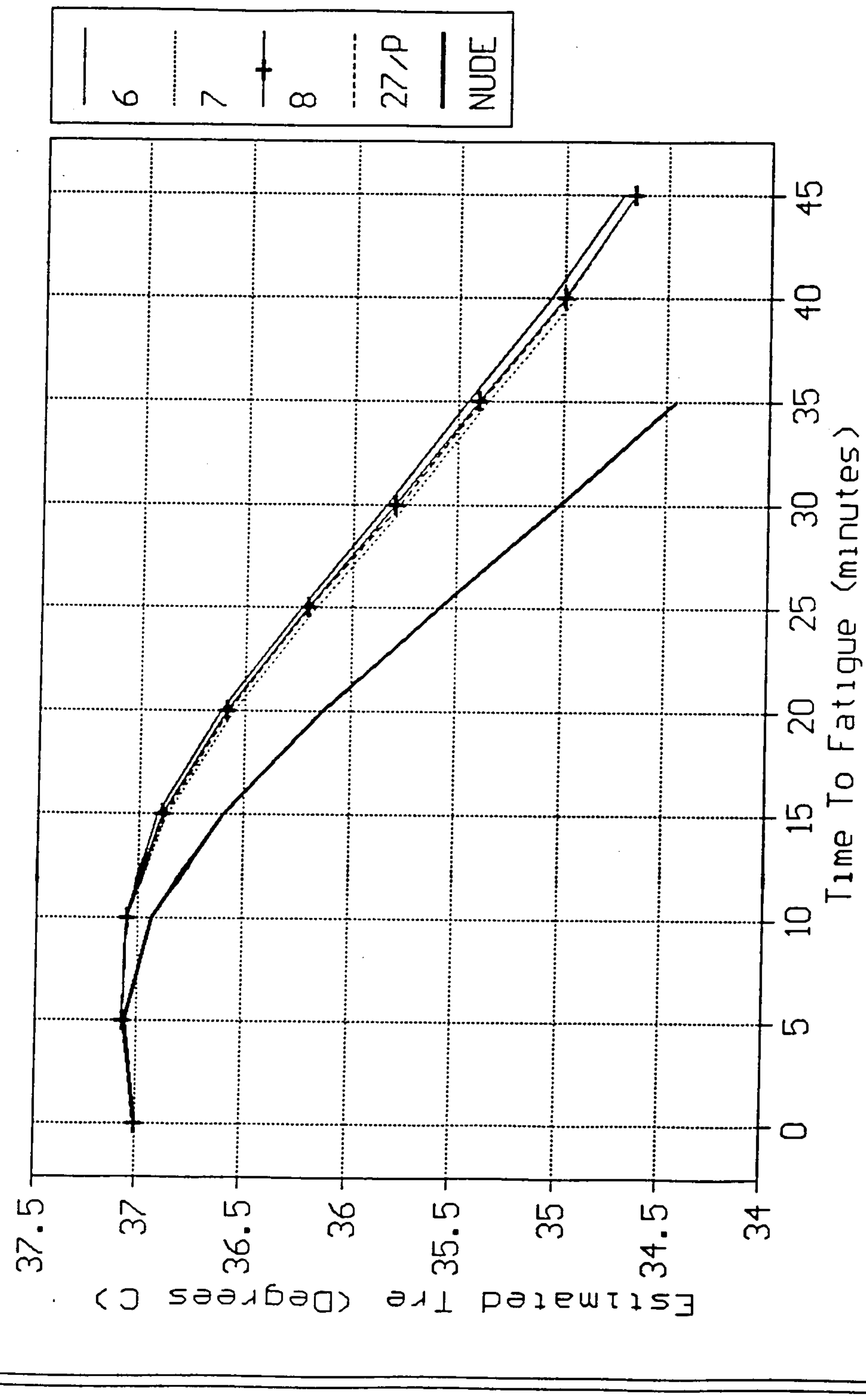

Figure 6. Estimated rectal temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by CORD.

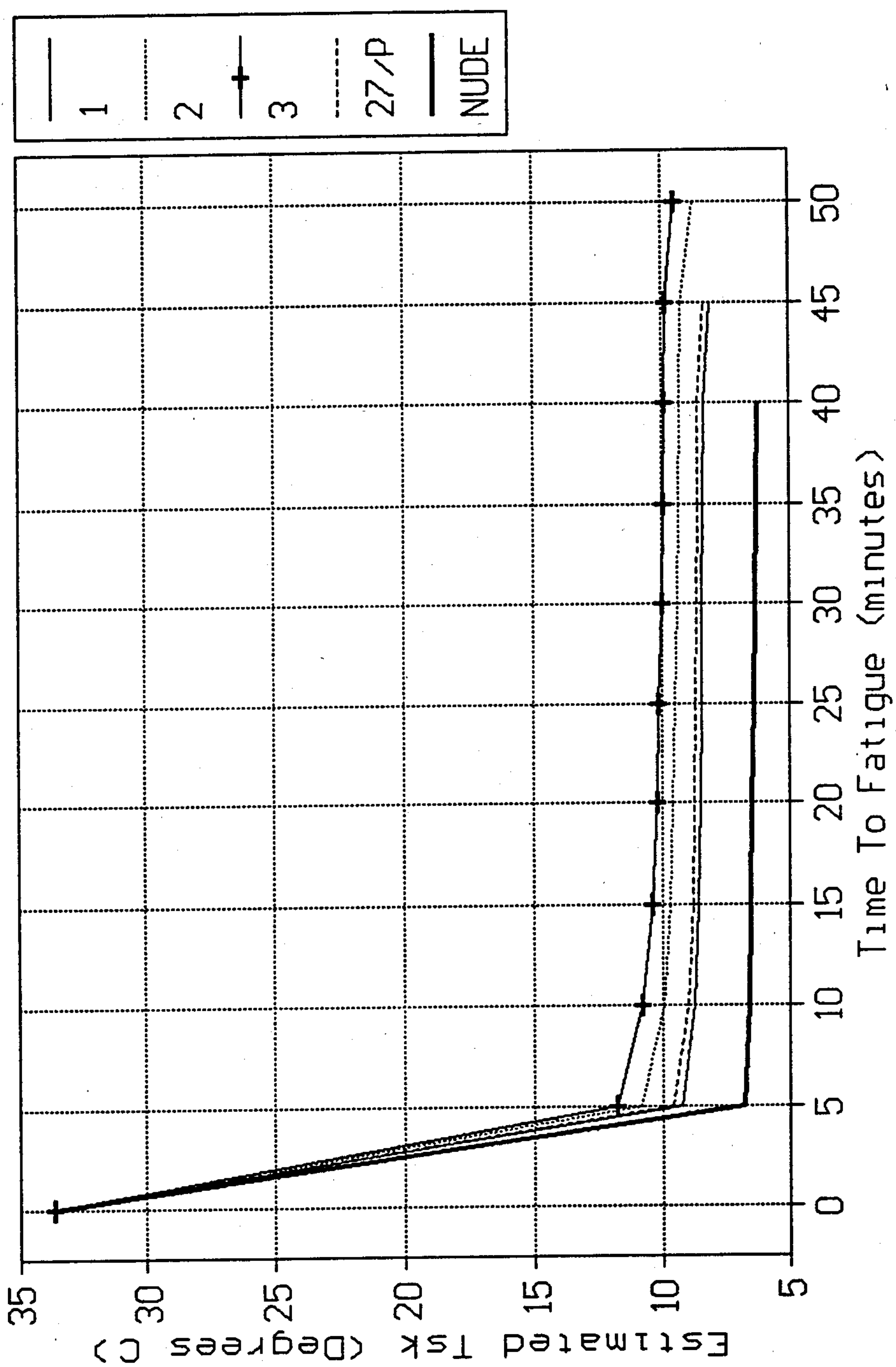

Figure 7. Estimated mean skin temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by Navy Natick.

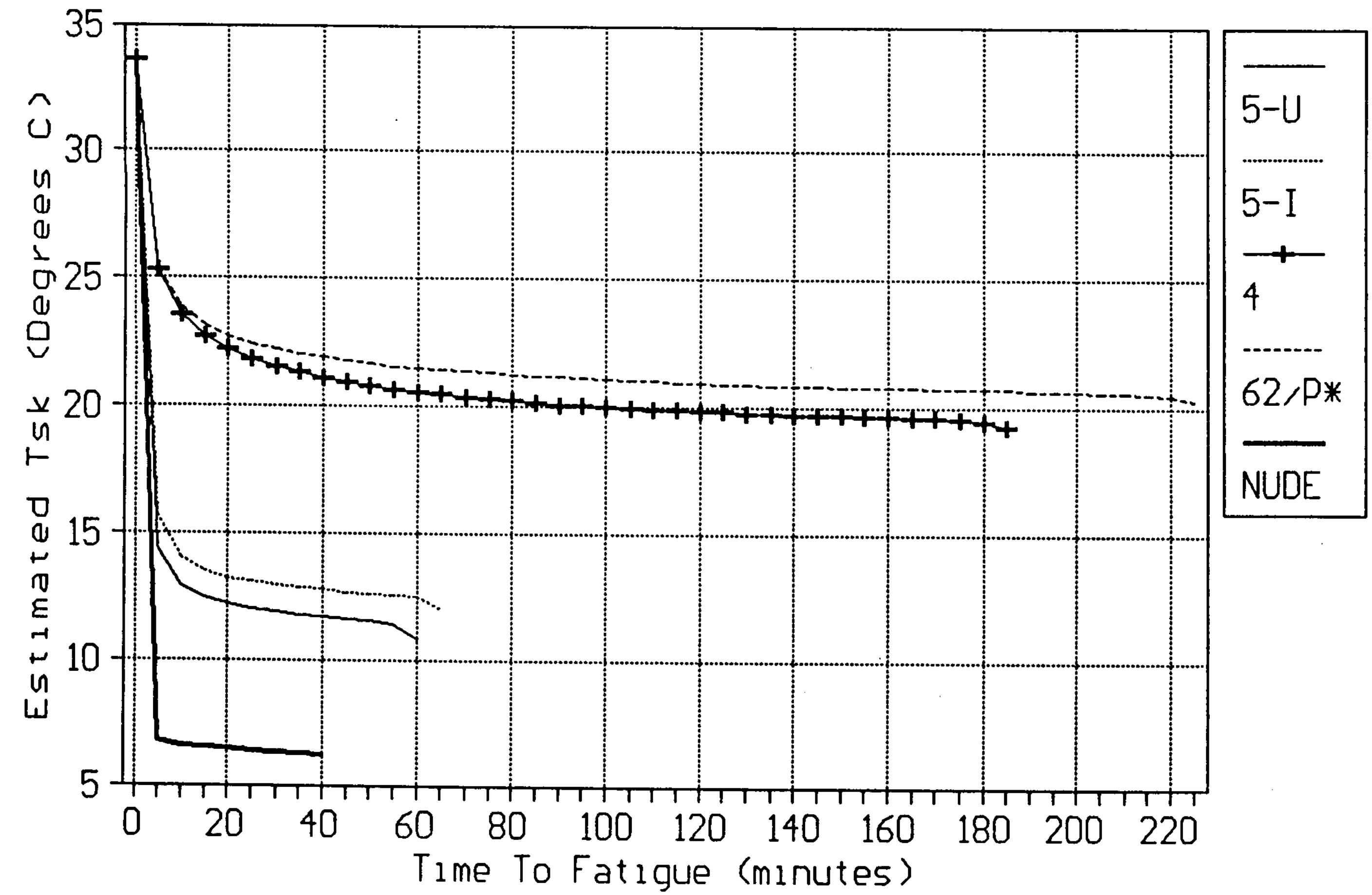

Figure 8. Estimated mean skin temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by CORD.
U: uninflated; I: inflated; *: CLO measured by Navy Natick.

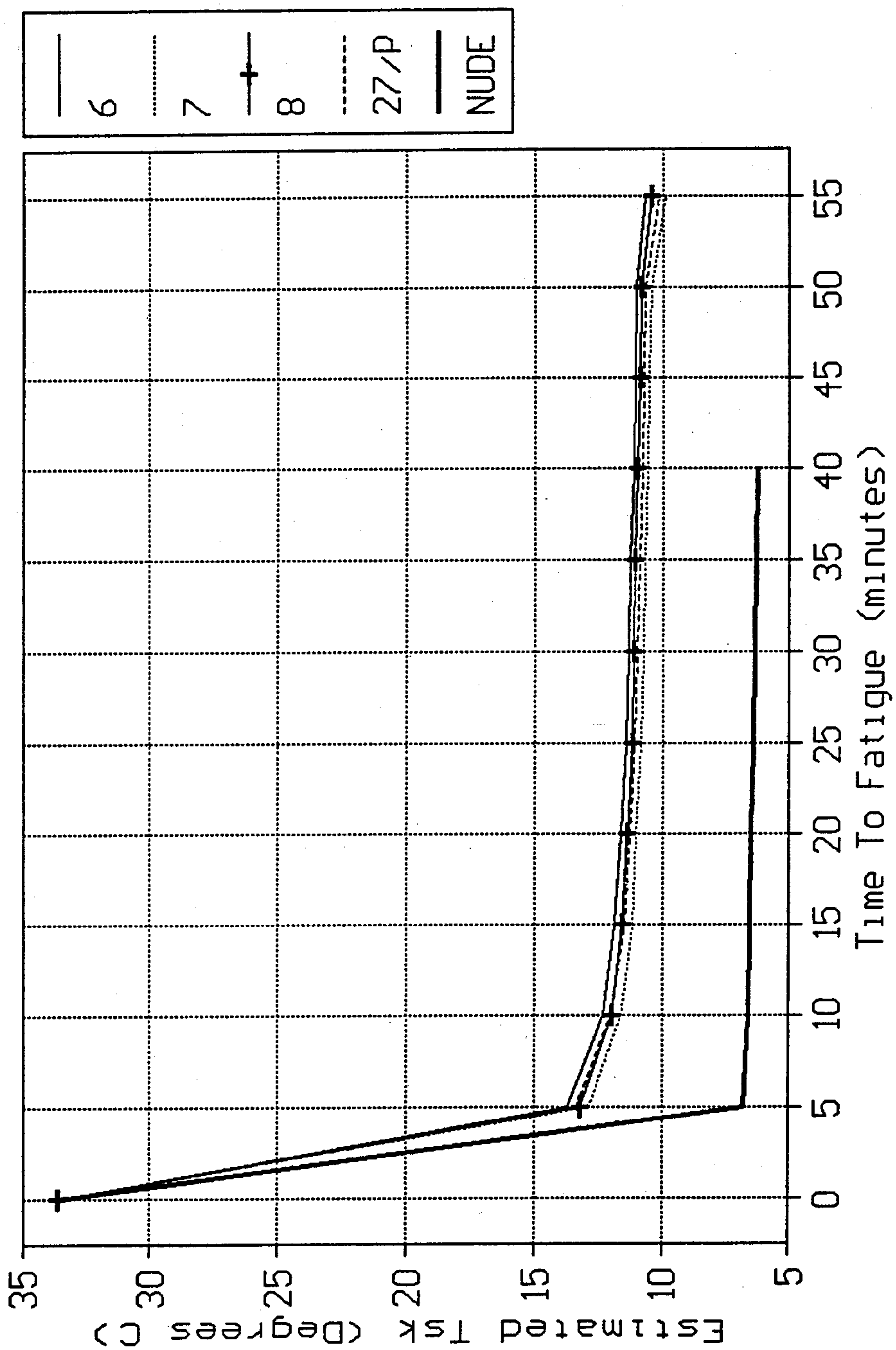

Figure 9. Estimated mean skin temperature during simulated 4.4oC CWI using ensembles whose CLO values were measured by CORD.

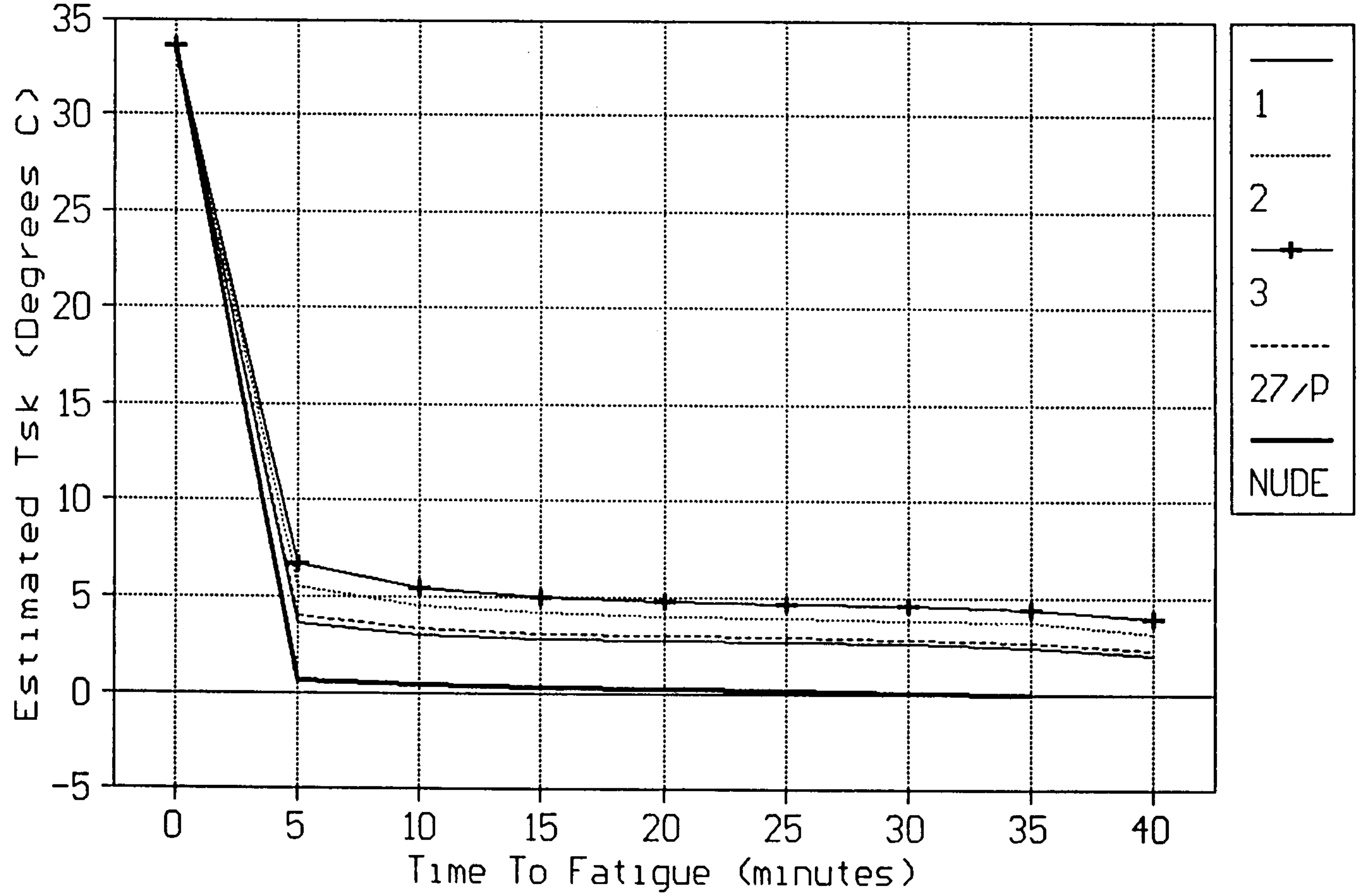

Figure 10. Estimated mean skin temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by Navy Natick.

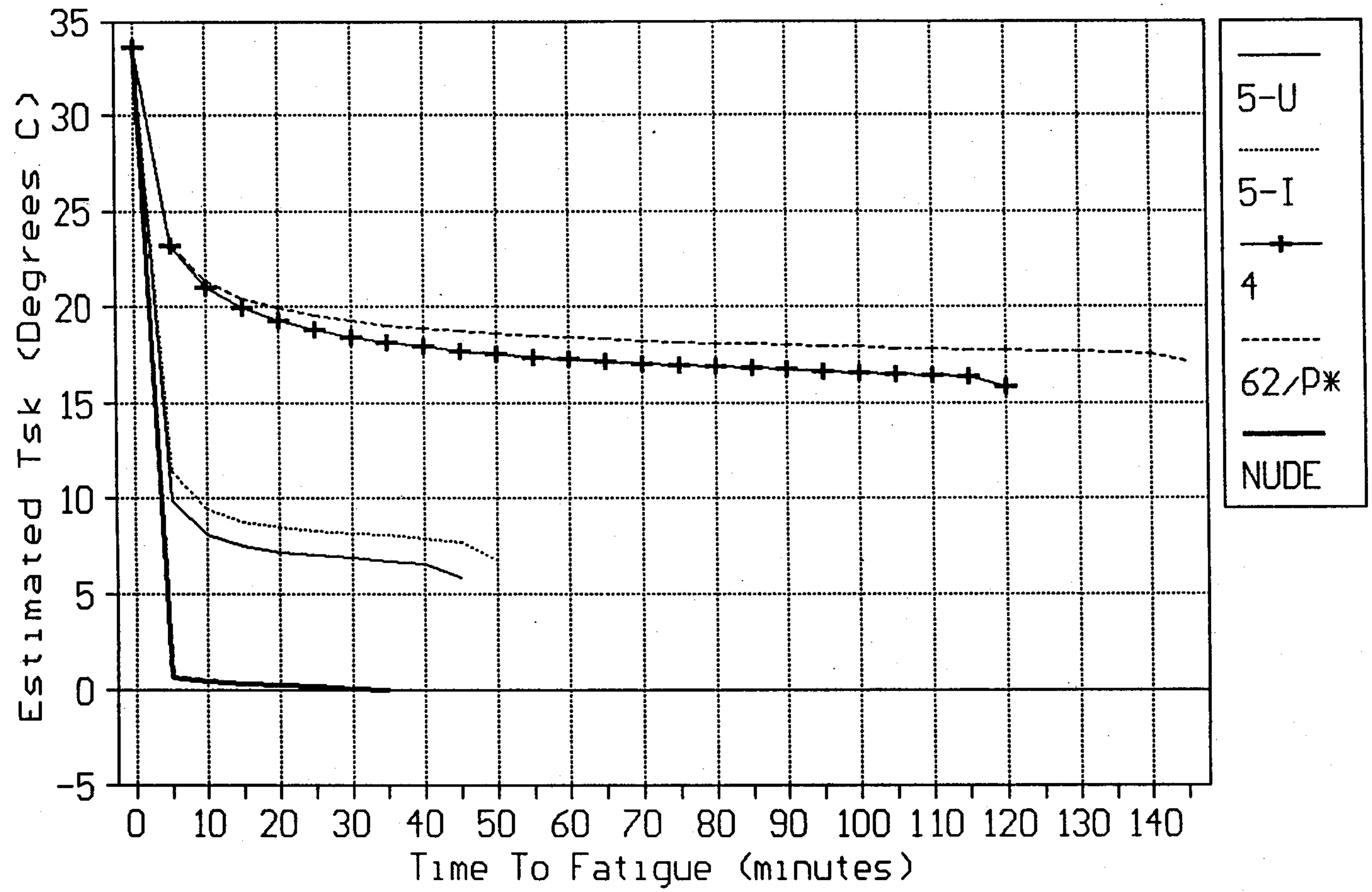

Figure 11. Estimated mean skin temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by CORD.
U: uninflated; I: inflated; *: CLO measured by Navy Natick.

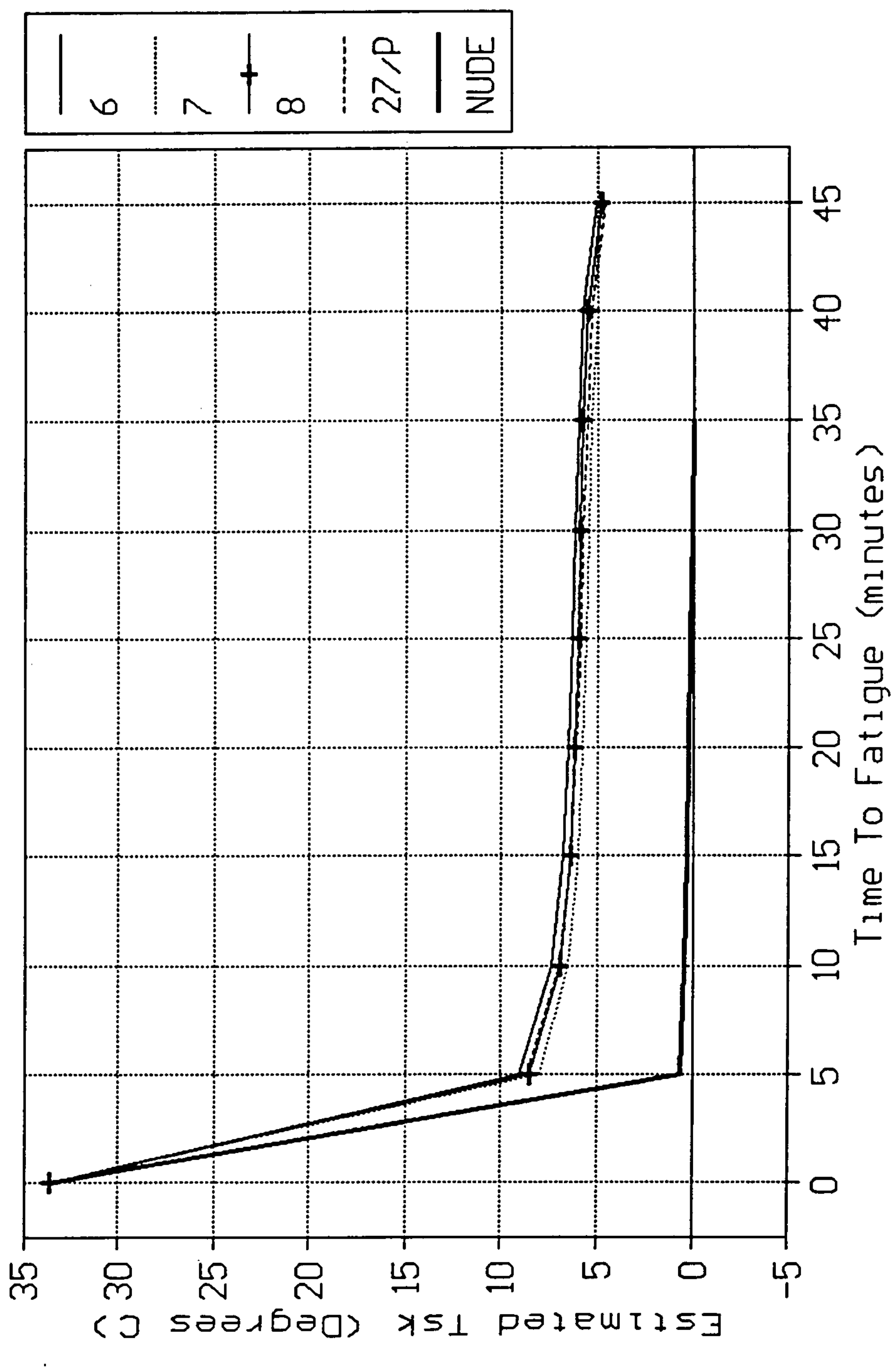

Figure 12. Estimated mean skin temperature during simulated -2.2oC CWI using ensembles whose CLO values were measured by CORD.

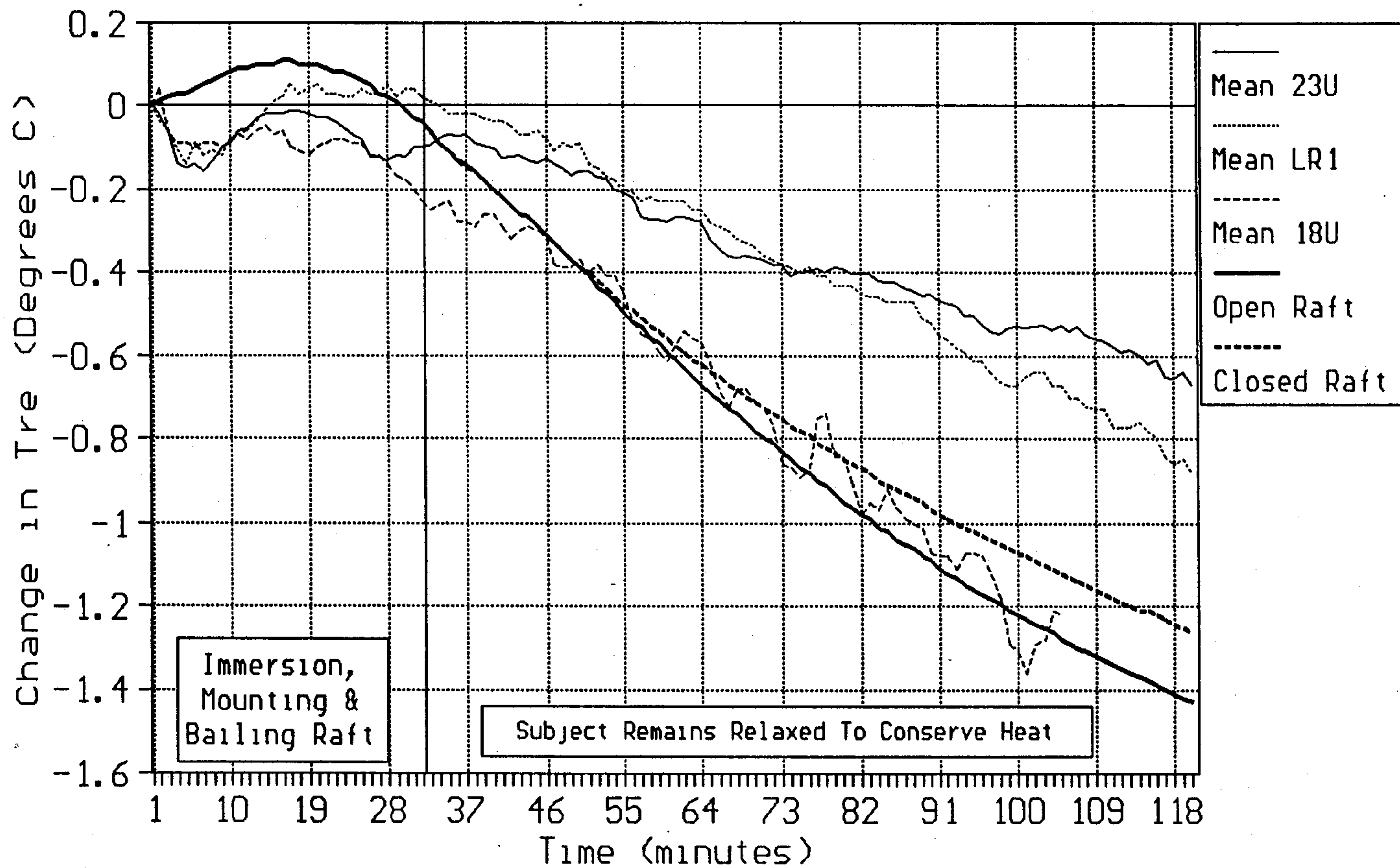

Figure 13. Comparison between THTM predicted change in Tre for simulated open and closed rafts and mean human values during 2 hr 4.4oC CWI in open (18U) and closed (LR1 and 23U) rafts.

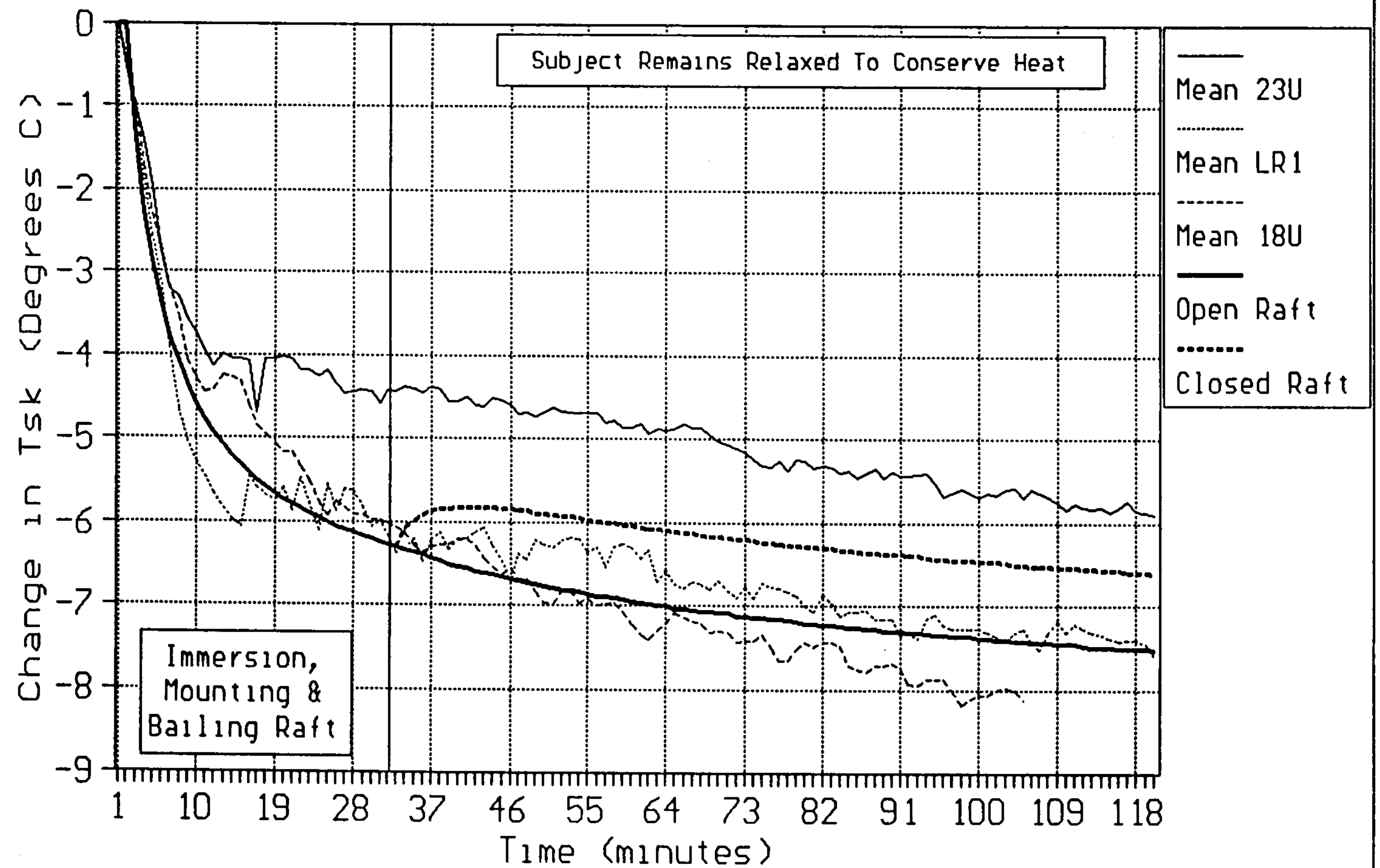

Figure 14. Comparison between THTM predicted change in Tsk for simulated open and closed rafts and mean human values during 2 hr 4.4oC CWI in open (18U) and closed (LR1 and 23U) rafts.

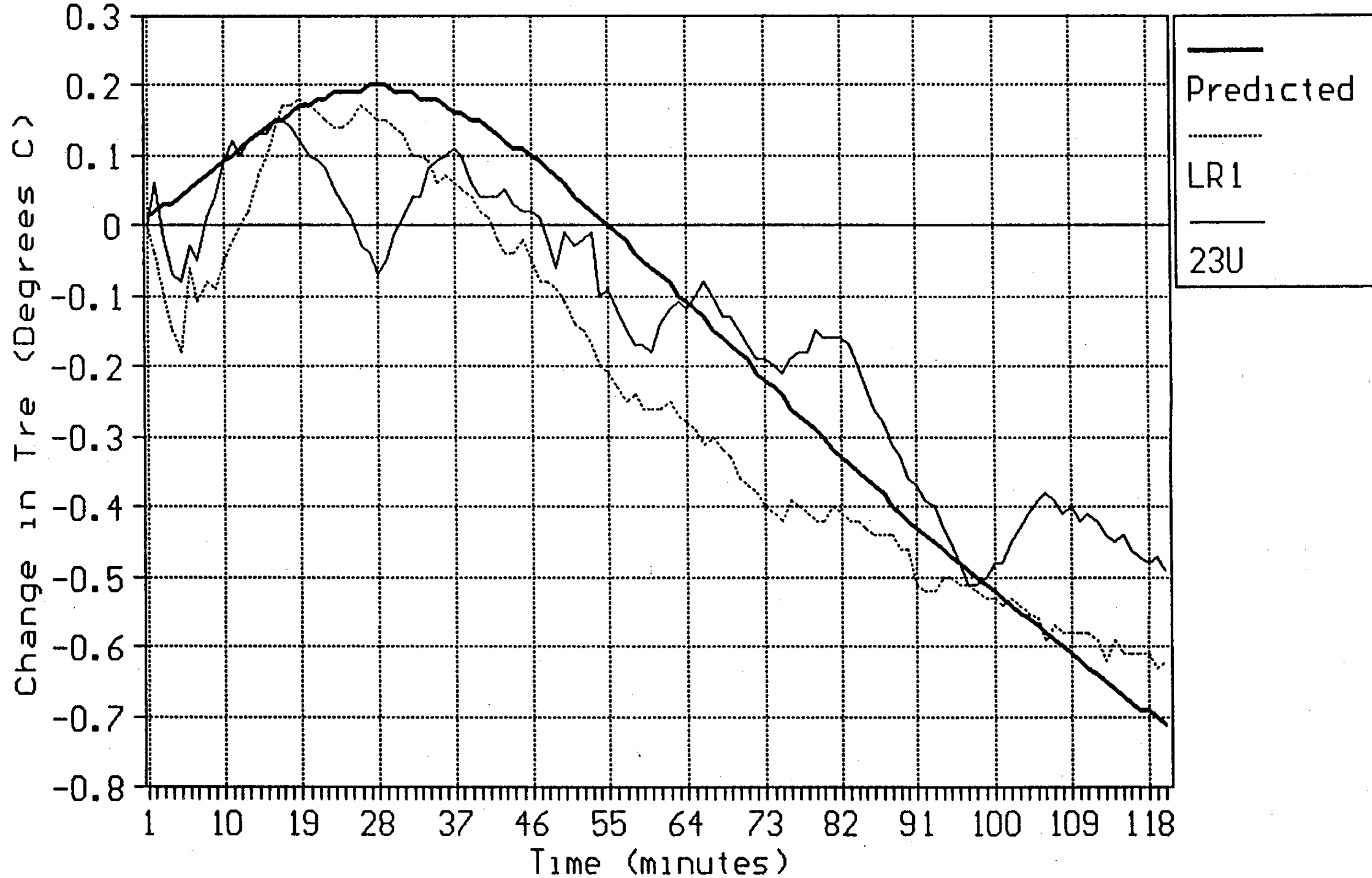

Figure 15. THTM estimated change in Tre for subject A as compared to actual subject A values during 2 hour 4.4oC CWI in closed rafts.

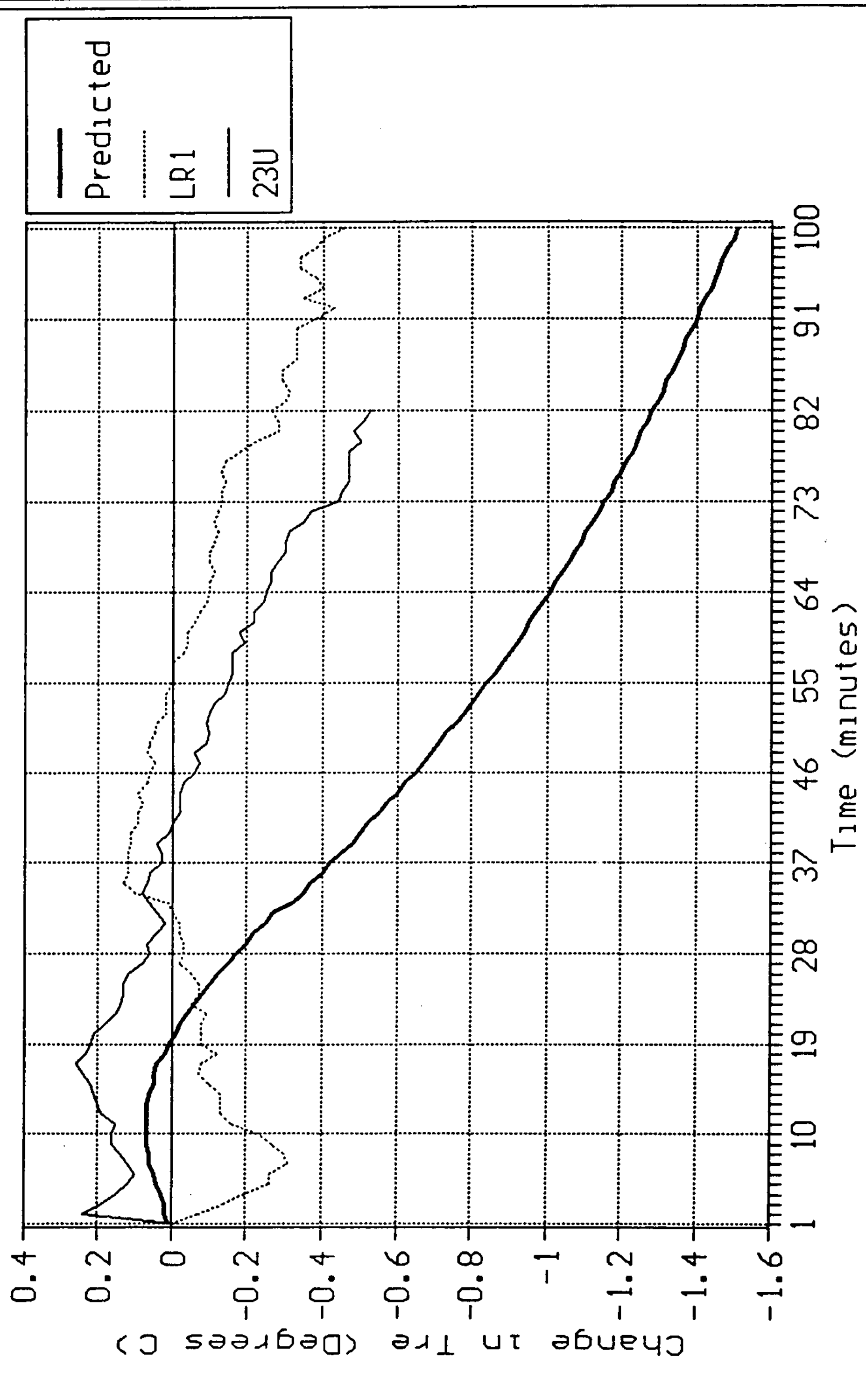

Figure 16. THTM estimated change in Tre for subject B as compared to actual subject B values during 2 hour 4.4oC CWI in closed rafts.

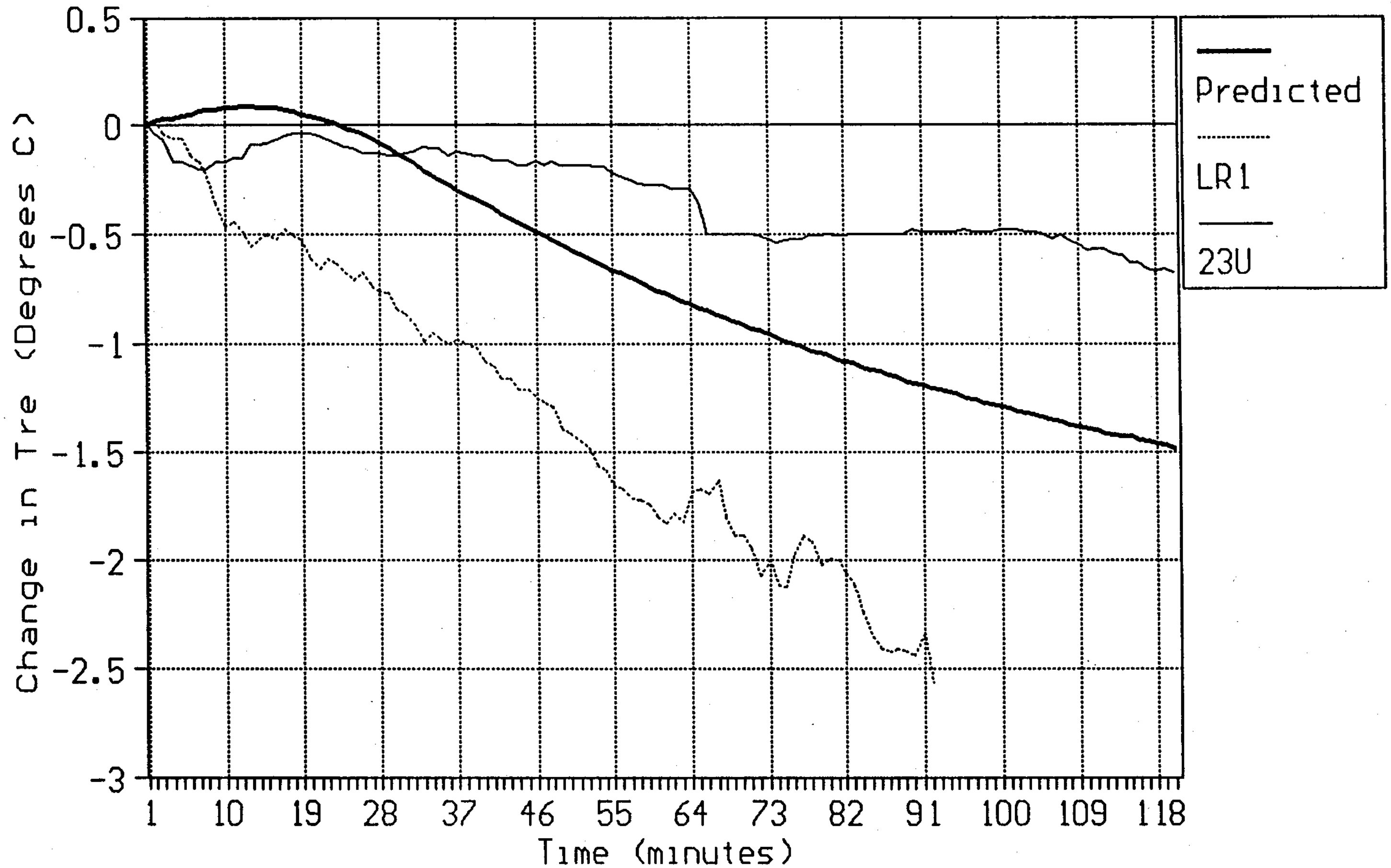

Figure 17. THTM estimated change in Tre for subject E as compared to actual subject E values during 2 hour 4.4oC CWI in closed rafts.

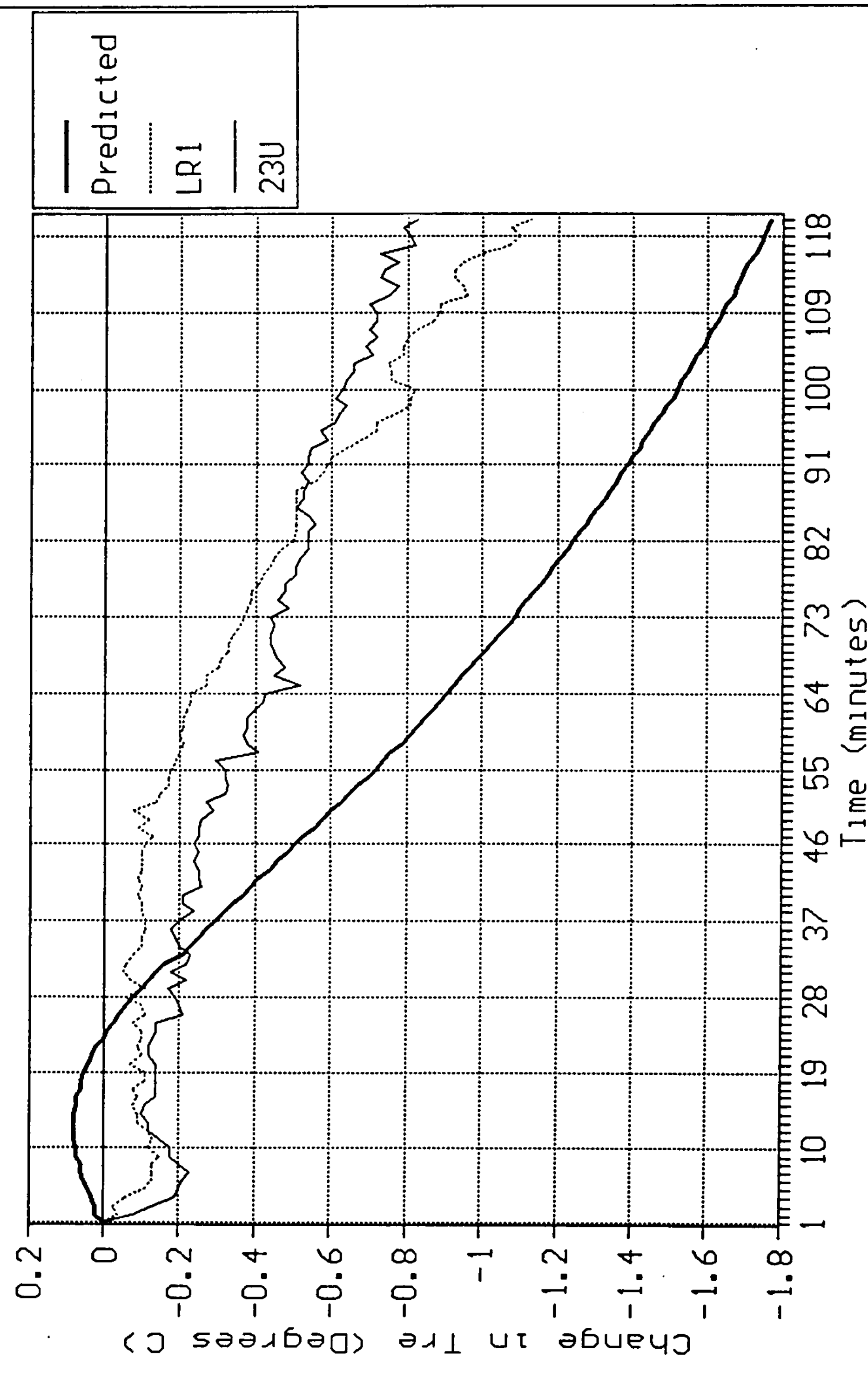

Figure 18. THTM estimated change in Tre for subject F as compared to actual subject F values during 2 hour 4.4oC CWI in closed rafts.

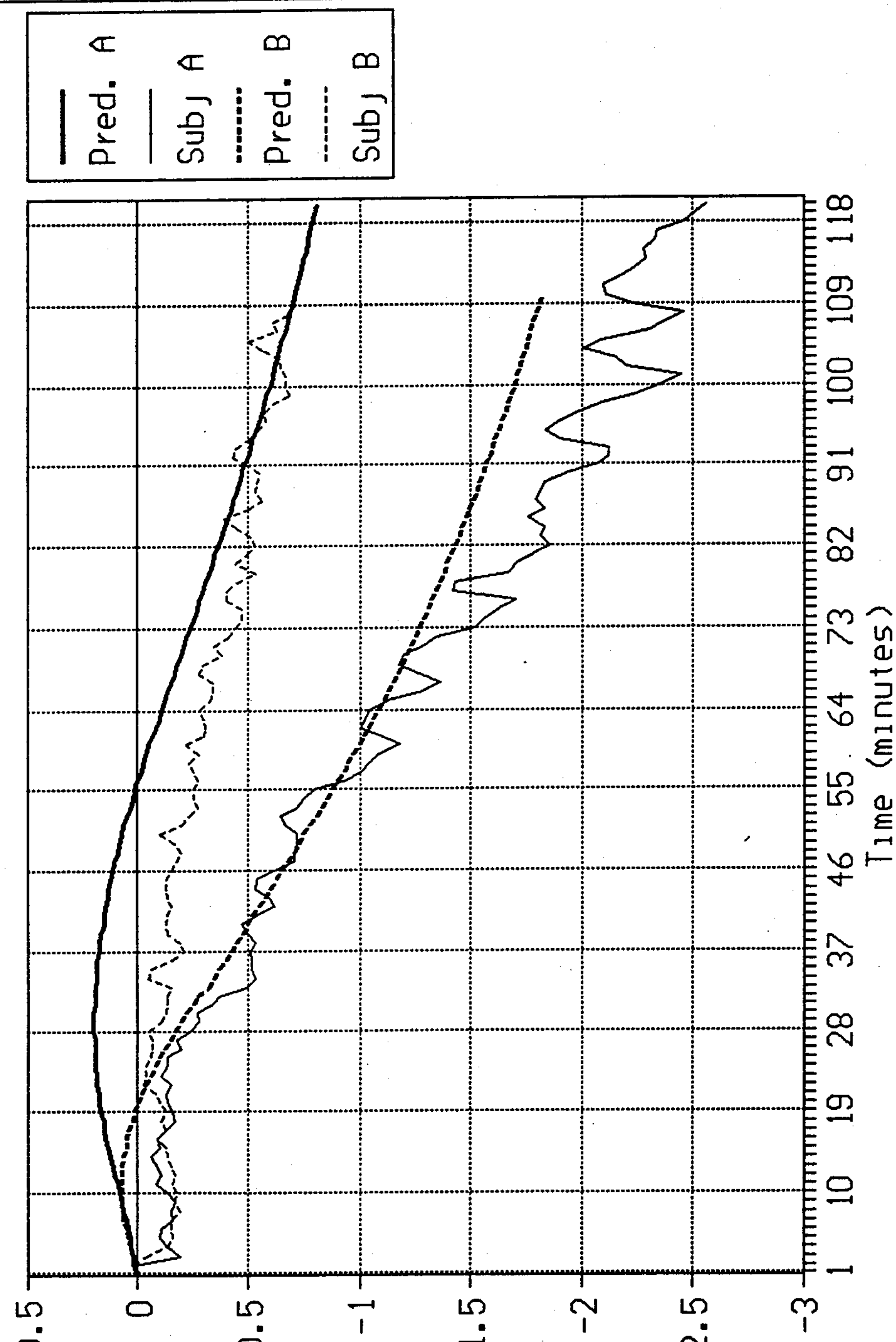

Figure 19. THTM estimated change in Tre for subjects A & B as compared to actual subject values during 2 hour 4.4oC CWI in an open raft.

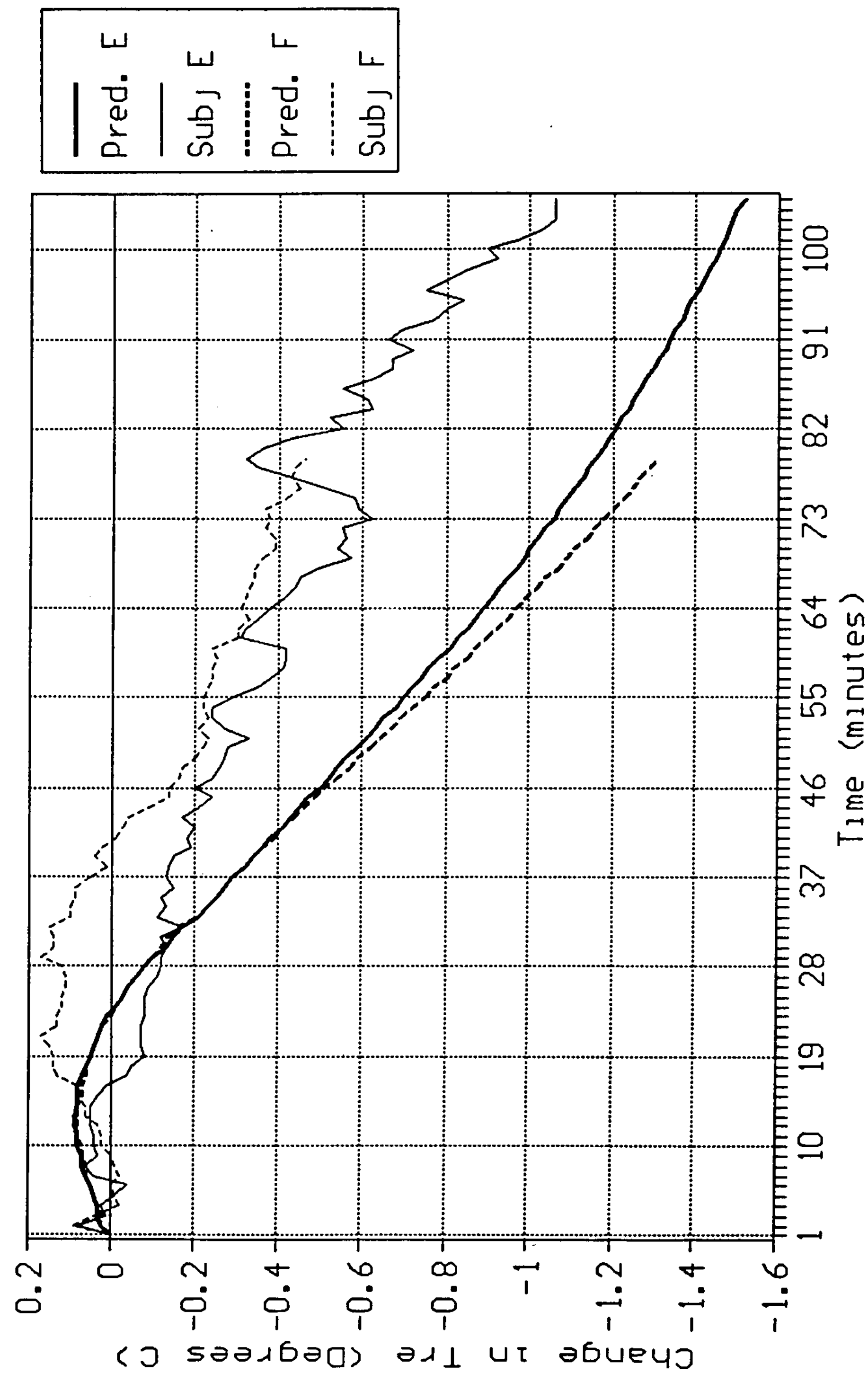

Figure 20. THTM estimated change in Tre for subjects E & F as compared to actual subject values during 2 hour 4.4oC CWI in an open raft.

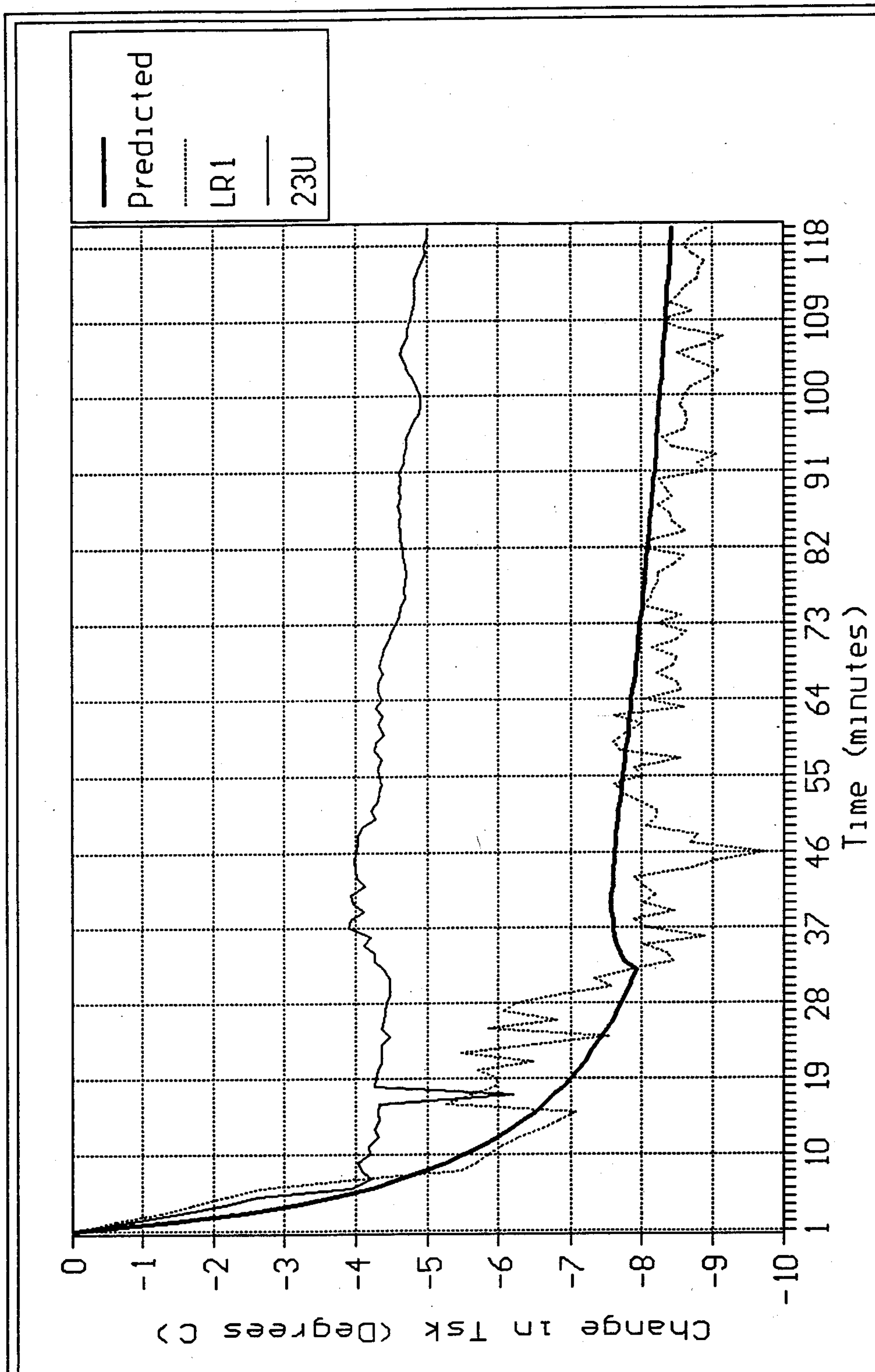

Figure 21. THTM estimated change in Tsk for subject A as compared to actual subject A values during 2 hour 4.4oC CWI in closed rafts.

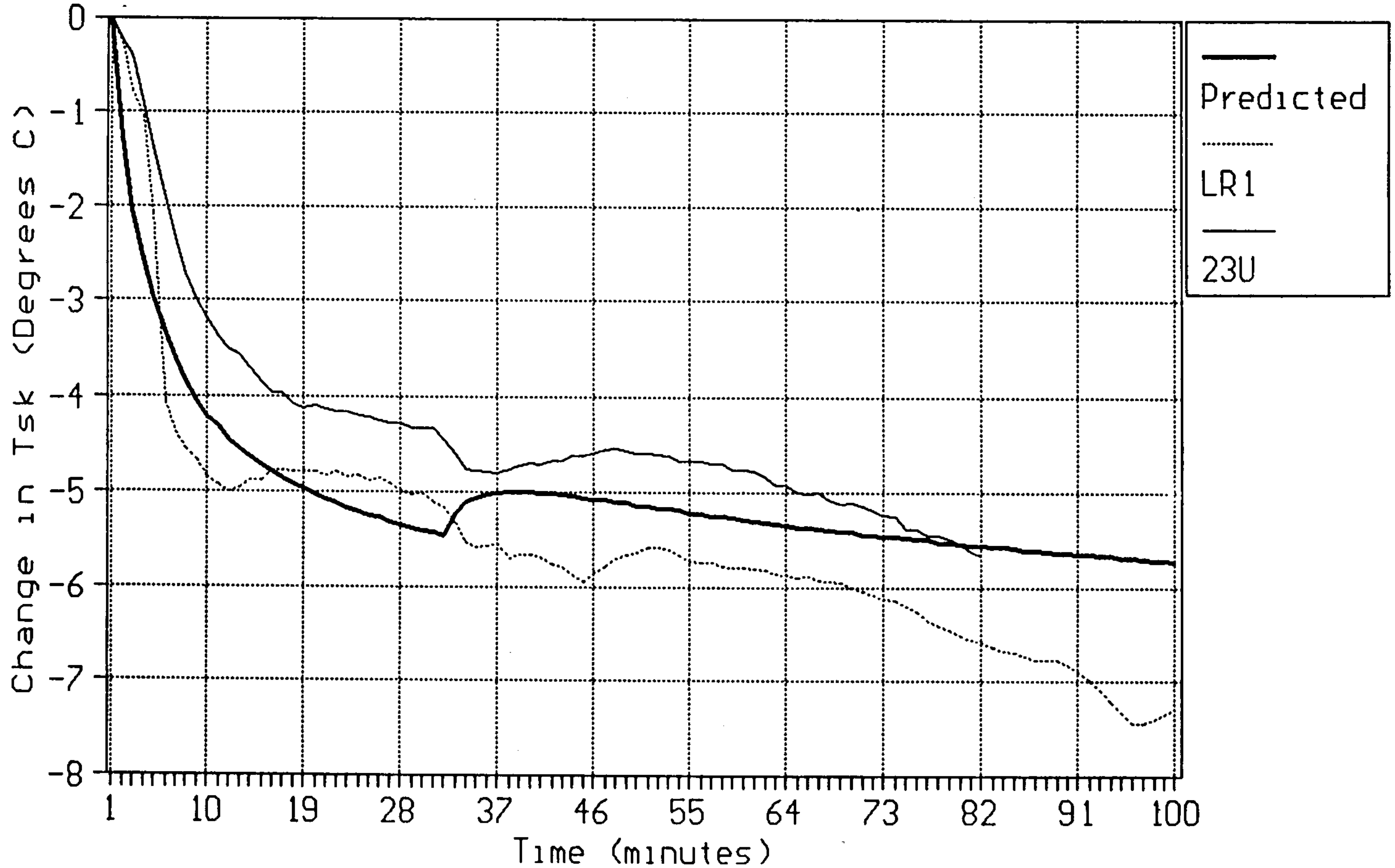

Figure 22. THTM estimated change in Tsk for subject B as compared to actual subject B values during 2 hour 4.4oC CWI in closed rafts.

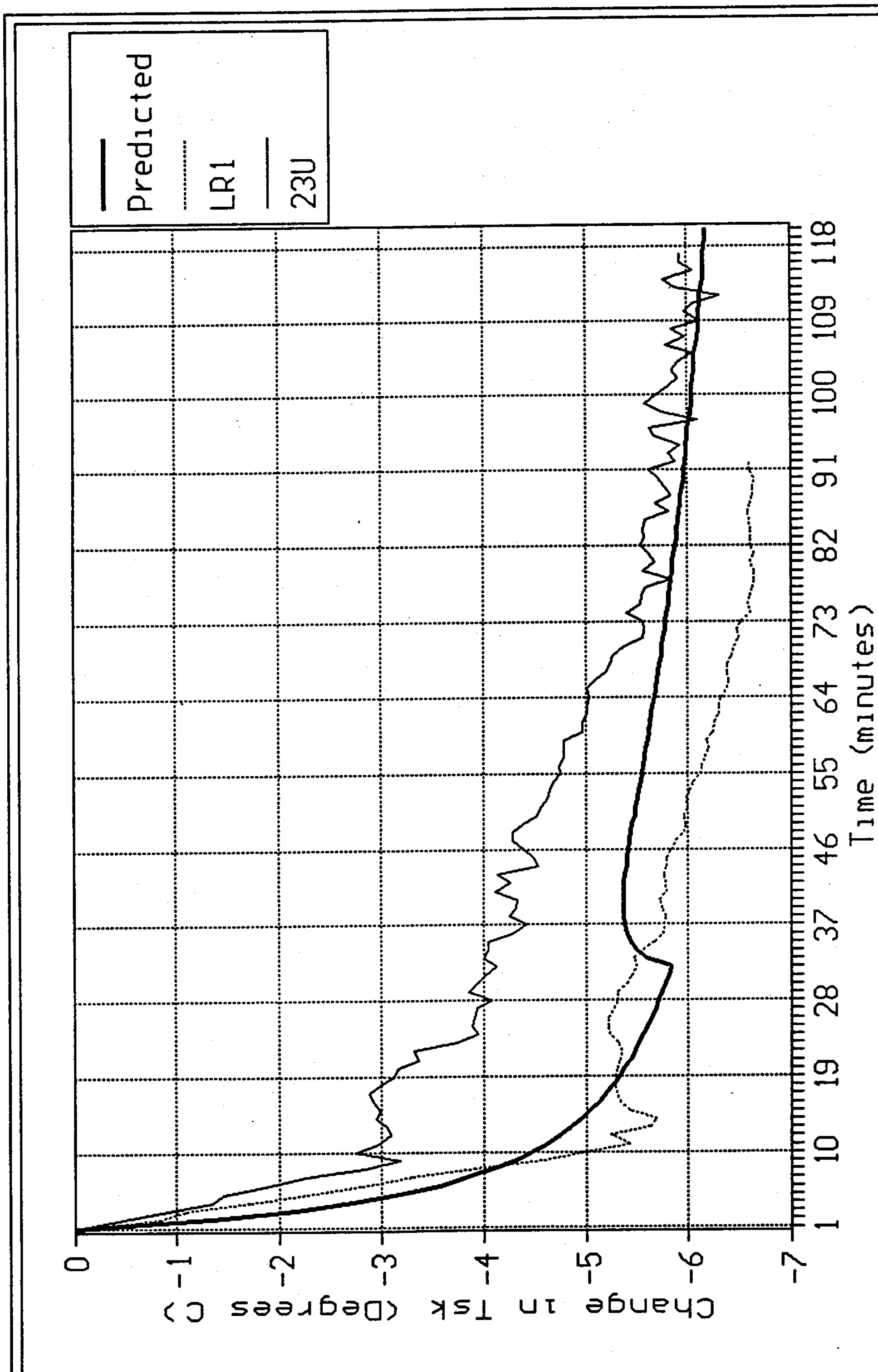

Figure 23. THTM estimated change in Tsk for subject E as compared to actual subject E values during 2 hour 4.4oC CWI in closed rafts.

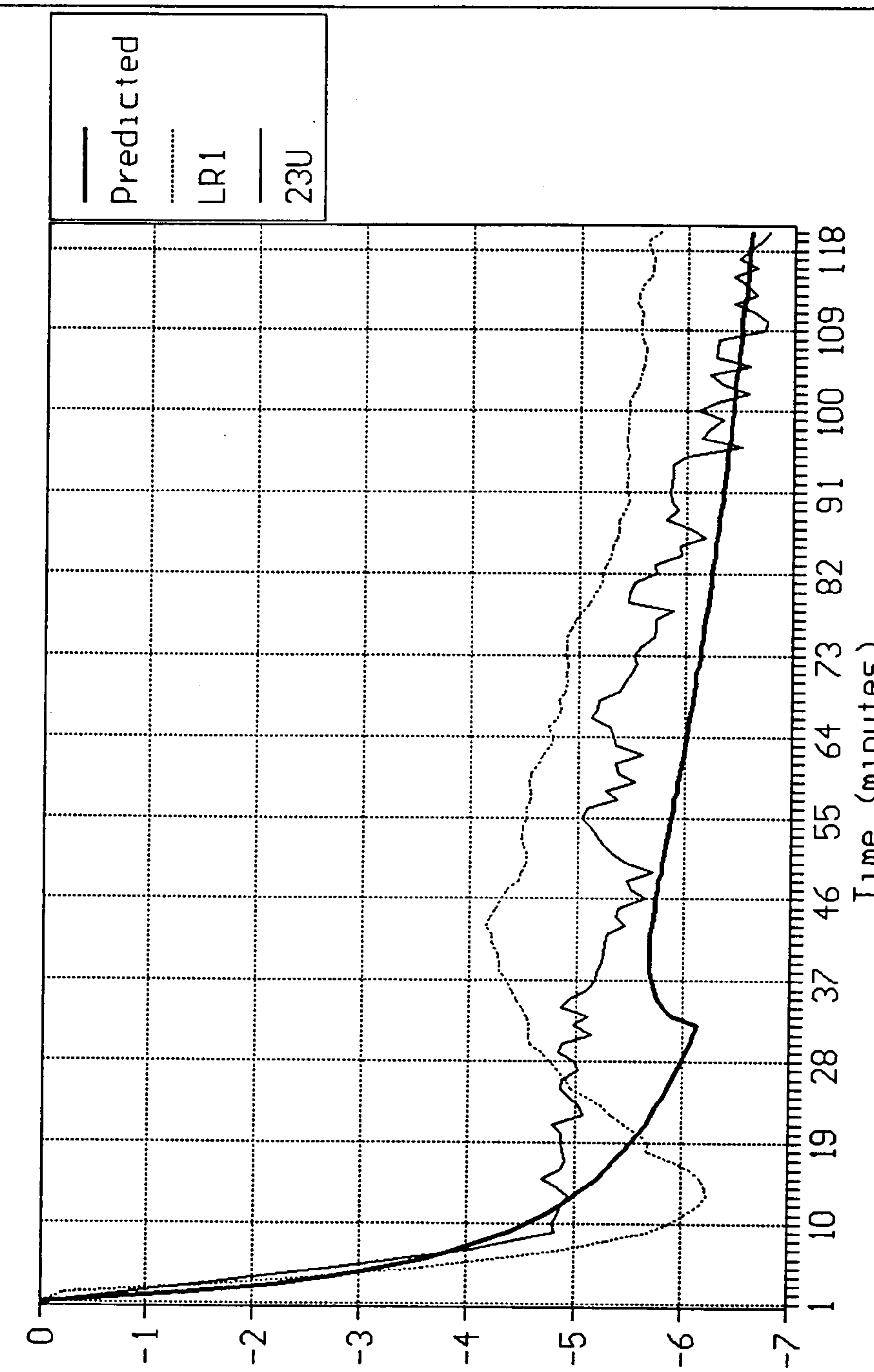

Figure 24. THTM estimated change in Tsk for subject F as compared to actual subject F values during 2 hour 4.4oC CWI in closed rafts.

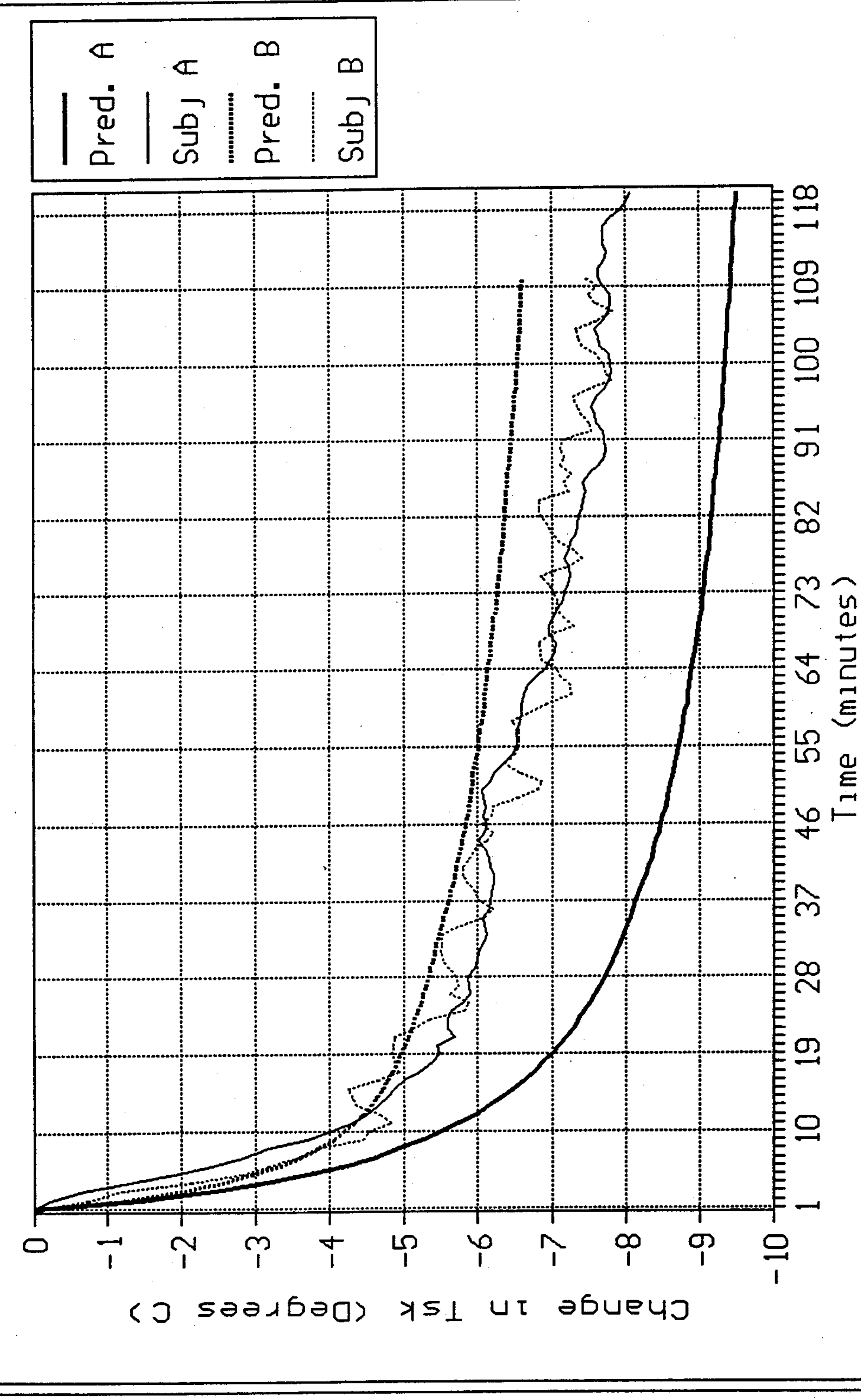

Figure 25. THTM estimated change in Tsk for subjects A & B as compared to actual subject values during 2 hour 4.4oC CWI in an open raft.

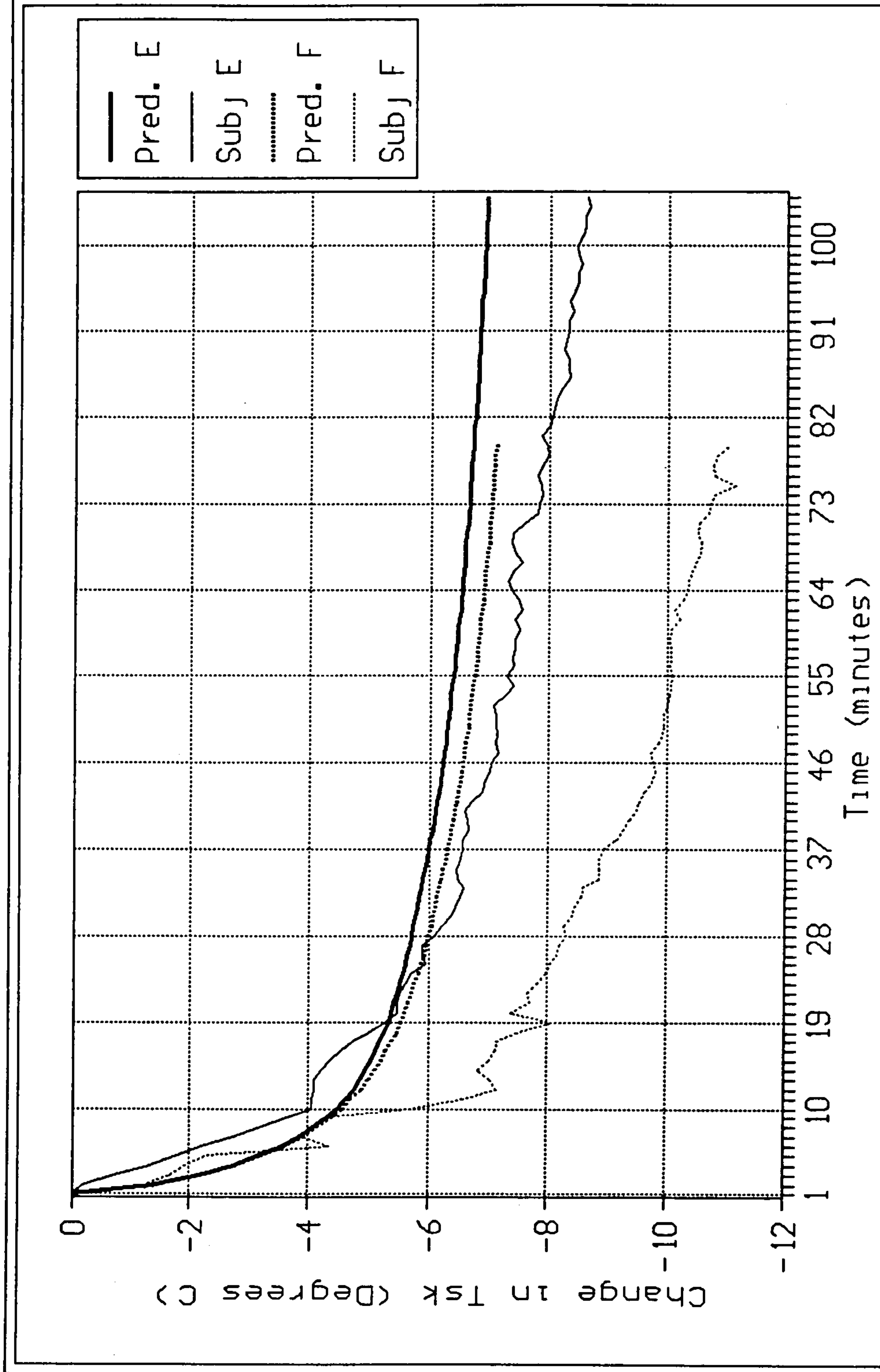

Figure 26. THTM estimated change in Tsk for subjects E & F as compared to actual subject values during 2 hour 4.4oC CWI in an open raft.

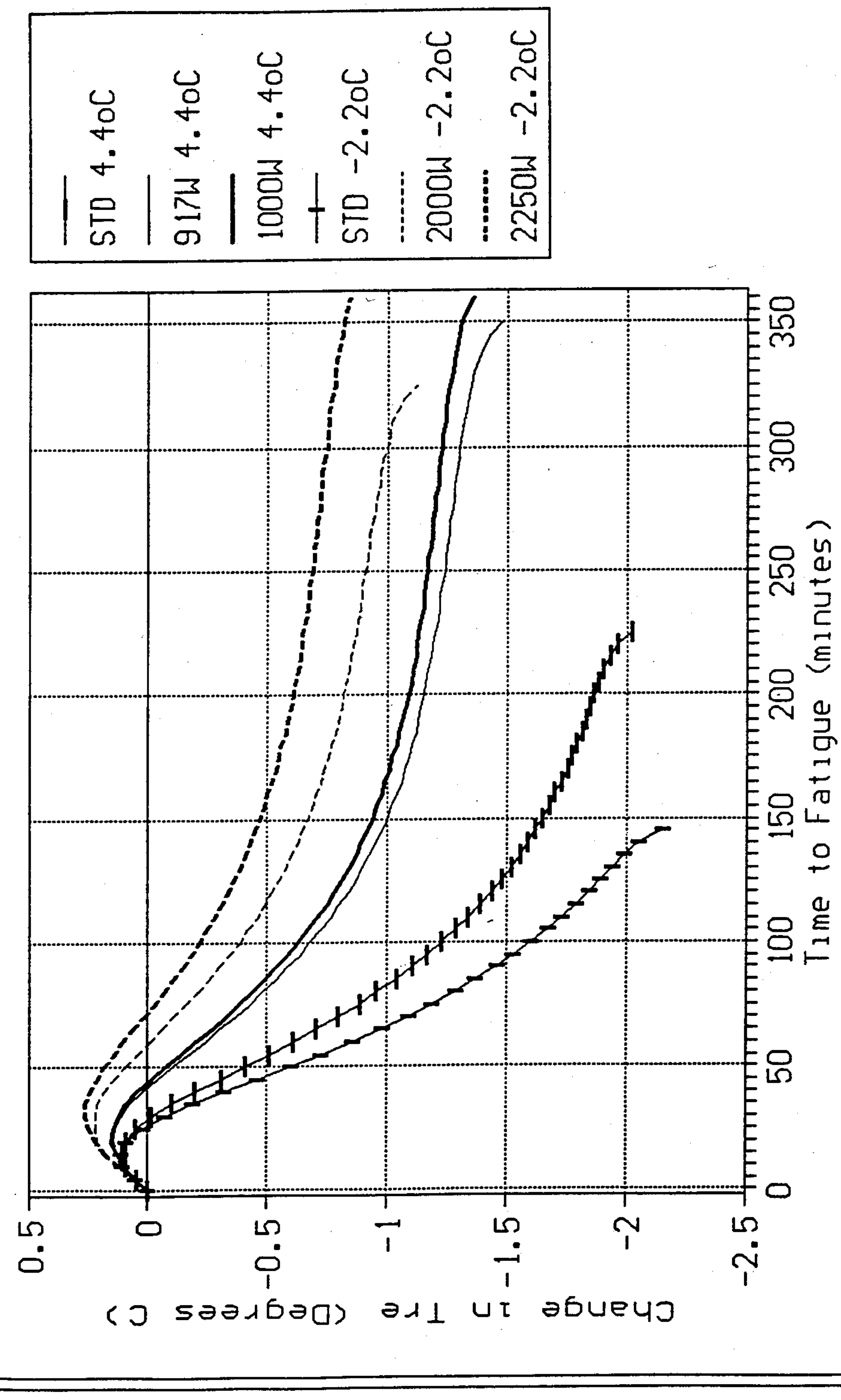

Figure 27. Effects of exogenous heating on THTM predicted change in Tre during 6 hr 4.4 and -2.2oC CWI while wearing a CWU-62/P. Values listed include 2 power output levels for each water temperature. Standard (STD) estimates are shown for comparison.

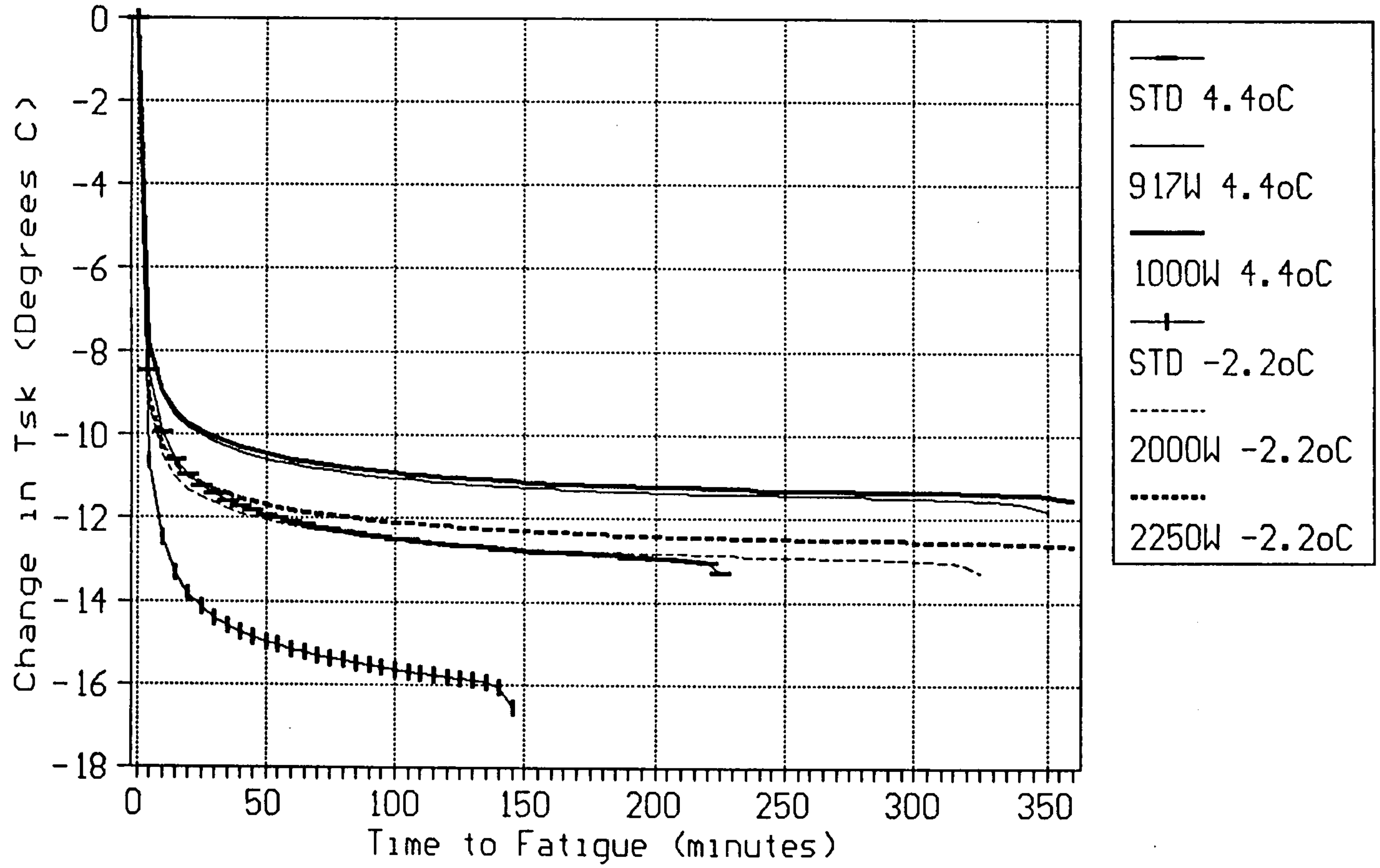

Figure 28. Effects of exogenous heating on THTM predicted change in Tsk during 6 hr 4.4 and -2.2oC CWI while wearing a CWU-62/P. Values listed include 2 power output levels for each water temperature. Standard (STD) estimates are shown for comparison.

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